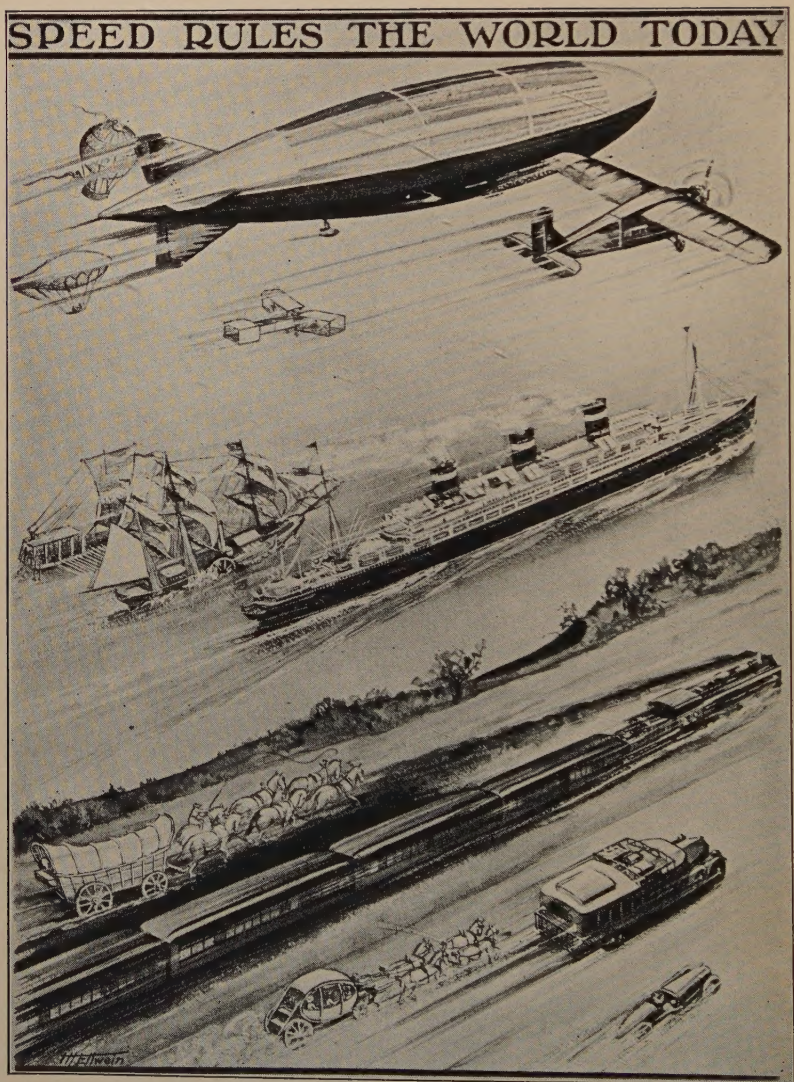
LIVING IN A WORLD OF SCIENCE

ENERGY AND POWER

MORRIS MEISTER



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LIVING IN A WORLD OF SCIENCE

ENERGY AND POWER

BY

MORRIS MEISTER

NEW YORK TRAINING SCHOOL FOR TEACHERS
COLLEGE OF THE CITY OF NEW YORK
AND
EDITOR, "THE SCIENCE CLASSROOM"

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TO THE TEACHER

We live in a world of science. Never before in the history of mankind have scientific knowledge, invention, and method affected so greatly every event and every act of daily life. Each day brings some new discovery, often so far-reaching in its human applications, that the science teacher is continually faced with the problem of interpreting the constant flow of scientific achievement.

Obviously, any significant understanding of our complex scientific environment must be based upon the fundamental concepts of science. These concepts become the sign-posts which direct the pupil through the maze of science experience and give meaning to the natural phenomena of the world in which he lives.

Any organized study of our environment which will explore pupil interests and possibilities of future science study can be effected most readily through application of the laws of learning. These laws, insofar as they are known and established, must operate also in the formation of good thinking habits and in an appreciation of the method of science, which is perhaps the outstanding contribution of science to the age in which we live.

"Living in a World of Science" is based upon the above-mentioned objectives of science teaching. It embodies the essence of many years of science classroom experience and of many contacts with the problems of science teachers in various parts of the country.

In its selection of content, the series is guided by three major principles:

I. There is general and wide acceptance of certain major units of study for the course in science.

II. Local conditions must be permitted to determine the degree of emphasis upon units and the order in which they are to be considered.

III. The further selection of material and activities for each unit must be based upon a set of criteria which are educationally valid.

Thus, in meeting the first of the principles above, the series includes such units as: Water, Air, Heat, Health, Electricity, Energy, Communication, Transportation, etc. Within its organization are also included the basic concepts of astronomy, earth science, the weather, and of plant and animal life.

The second guiding principle has resulted in a division of the book into four parts, called books. This makes for flexibility. Also, it minimizes the formidable aspect of so many of our science textbooks, which seem to be far too large for one volume and too small for adequate treatment of all that is included.

In complying with the third of the principles set forth above, the following criteria were applied by a committee of science teachers, in determining the most desirable science subject matter:

1. To what extent can the item of content be taught objectively? (Weight 4.)

2. To what extent does the item interest the pupil? (Weight 3.)
3. To what extent is the item adapted to the abilities of the pupil? (Weight 2.)
4. How frequently does the item occur in the normal experience of the pupil? (Weight 2.)
5. To what extent does the item represent a knowledge or skill which the pupil will find of value when an adult? (Weight 2.)

From this somewhat objective method of selection, a body of highly educational content emerged. The sixty items of greatest worth, as indicated by their final numerical ranking, became the basis for the material presented in this series.

The unifying thought around which "LIVING IN A WORLD OF SCIENCE" has been organized is that the pupil begins with a study of the science which contributes to *basic life needs,* after which he considers the *improvement of life through the utilization of science.* Thus, Book I deals essentially with Water and Air as basic life needs and Book II with Heat and Health as basic life needs. Book III in its development of Magnetism and Electricity and Book IV in in its treatment of Energy and Power stress the part that science is playing in making life more comfortable, more convenient, and more interesting.

Within each book, the organization centres around sixteen or seventeen units or major concepts. On the assumption that the school semester rarely offers more than seventeen "working weeks," a chapter a week becomes a feasible rate of achievement for pupil and for teacher. Thus, the four books provide adequately for a two-year course in science.

The development of each unit in each of the four books may be readily understood from a brief perusal of the Table of Contents. We begin with an Approach, designed to explore and arouse interest, after which the "steps" or contributing concepts are set forth in simple and complete sentence form. Each of the "steps" presents a discussion which takes its origin from an experiment or a series of experiments that can be performed by pupil or teacher at the demonstration table. The apparatus in every case is such as can be made with inexpensive and readily available materials. When the major concept has been established through demonstration, discussion and pupil activity, a number of outgrowths are suggested. Different pupils will be stimulated by different problems. These outgrowths are of great importance in the learning process. Indeed, effective learning is dependent upon them. Further explanation of this feature of the book is given below.

SPECIAL FEATURES

1. *The Approach to the Unit*

The author is in sympathy with the practice of unit introduction by "pretest," "survey questions," "over-view," etc. However, experience indicates that the same ends are sometimes better served by the use of biography, science "fiction," and adventure. Each unit or chapter has, therefore, been introduced with a science "story." The aim in this type of approach is to provide the pupil with several pages of interesting reading. The effect is to raise a problem and to motivate the development which follows.

2. *The Page of Problem Pictures*

Each unit or chapter closes with a page of problem pictures. If the important ideas have been mastered, this page stimulates further pupil activity. The pictures may raise a question to be answered, a subject to be investigated, an experiment to be performed, or a puzzle to be solved. Pupils are assigned to these problems so that they may report the solutions to the class.

3. *How Much Do I Remember?—A Review Test*

Here the material of each unit is reviewed in one or another form of "short-answer" type of test. The author has not limited himself to one style of test. In fact, he has deliberately made use of variety in order to suggest possibilities to the teacher in the matter of test construction. The uses to which this feature of the book may be put include periods of directed study and achievement-testing of minimum essentials.

4. *Things to Read About and Think About*

Toward the close of each unit the pupil finds several paragraphs of brief description, which open new fields for thought and investigation. If he is interested, he may find supplementary reading material in the books referred to and on the pages mentioned. Three well-known and popular reference books have been used for these supplementary readings. It is suggested that opportunity be given pupils to report on their readings and investigations.

5. *Things to Do and Make*

This section closes each unit or chapter. It is especially designed for activities involving construction and experimentation. Pupils and teachers will find here a fruitful source of new demonstrations, home experiments, and science club activities. The specific page references for each project are to nine or ten books which may be made available in the class or school library.

It is important to note that the four features last mentioned need not be applied to all pupils; nor need all of the activities be included for any one pupil. They are intended as stimuli for the varied interests and abilities which are to be found among pupils under normal teaching conditions.

M. M.

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TO THE PUPIL

This book is written to help you study science. You may become so interested in the subject that you will want to be a scientist. We hope so, because the world expects to find among you, men and women who will continue to solve the mysteries of nature, yet unsolved. But even if you do not become a scientist, you need to know about science in order to live properly in this modern age. Especially, you must learn to think like a scientist in many of the problems which face you every day.

How does a scientist proceed to find out about things? He employs two methods. First, he tries to find out if any one already knows the answer to his question. The simplest way of doing this is to read the writings of other men of science. Of course, he need not believe everything he reads. Many books have been found to be wrong. Yet, he can learn much from some one else's experiments, particularly if he has confidence in the writer and knows him to be a careful thinker. And second, he can arrange his own experiments to check the conclusions of others; or, if no one knows the answer, he can try to discover it himself. This is by far the best method, for it leads to new facts, new discoveries, new inventions and new experiments.

This book helps you to follow both methods. Your science teacher begins the work in science by performing certain experiments and demonstrations. Many questions and problems arise. After some discussion of these with your classmates and with your teacher you read the chapter which deals with the subject in question. In the course of your reading, which may be done at home, you may wish to try out the experiments suggested by the book, to see if they "work." At the end of each chapter, you find a page of *Problem Pictures*. Each diagram or photograph raises a question or suggests a new experiment. If you have understood the chapter, you can readily answer the questions and perform the experiments.

Then comes a *test*. How much do you remember of what you have read? Mark yourself on this test, and do not be satisfied with less than 90 per cent.

When you have succeeded with the "*How Much Do I Remember*" test, you are ready to go further. If you have time and if you are interested, look at the remaining two lists at the close of each chapter. They open up new fields for study, raise new problems and suggest new experiments. One of these lists is called "*Things to Think About and Read About.*" The second is "*Things to Do and Make.*"

In the first list you discover that what you have read in the chapter is only a beginning. Pick out one question that interests you very much and set out to find an answer. Perhaps, when you have discovered the answer, your teacher will let you report it to the class. If you have time try another. As you continue to do this, you will learn to read books and to use books of all kinds. You will become familiar with the use of the *Index* and the *Table of Contents*. Of the many books which may be helpful to you in your search for answers, there are three which we hope you can find in the library. And so, for each question, we direct you to a particular page in one or more of these books. Here are the books:

O. Compton's Pictured Encyclopedia (F. E. Compton & Co., Chicago).
P. Book of Popular Science (The Grolier Society, New York).
K. Wonderbook of Knowledge (J. C. Winston Co., Philadelphia).

In the second list you find interesting things to do and to make. Just as each chapter leads to new things to think about, so it also leads to new experiments to try out. Since you will need some assistance in carrying out these projects, we have selected nine books of experiments to which we refer by giving the exact page in each case. We hope you can borrow one or more of these books from your school or local library. This is the list:

A. Easy Experiments in Elementary Science, by McKay (Oxford University Press).
B. Experimental Science, by Collins (Appleton).
C. Scientific Amusements, by Tom Tit (Nelson).
D. The Boys' Book of Experiments, by Collins (Crowell).
E. Boys' Home Book of Science and Construction, by Morgan (Lothrop, Lee and Shepard).
F. Magical Experiments, by Good (David McKay).
G. Things to Make, by Williams (Nelson).
H. The Boy Mechanic, Book 2 (Popular Mechanics Co.).
I. Light Experiments, by Gilbert (A. C. Gilbert Co., New Haven, Conn.).

INTRODUCTORY CHAPTER

LET US TALK THINGS OVER

You have been studying science for some time now. We take it for granted that you are interested in watching experiments and in performing them yourself. Perhaps, too, the wonders and inventions of modern science appeal to you. But if you think, for a moment, of the different topics which have been considered in class, you will see that we have been trying to help you get a better understanding of the world in which you live.

First, we studied about *Water*. We learned how important it is to life, how we make sure to have a good supply of it always, and how we use it in manufacturing, in transportation and in other ways. Then we considered the topic, *Air*—another basic life need. After learning what air is made of we became interested in the many ways in which air may do useful work. The problem of travelling through the air led us to a study of the airplane and we spent some time on sounds which also travel through the air.

Later we came to the subject of *Heat;* for this too is essential in our lives. Foods and fuels, heating and cooling, boiling and freezing are all important things about which we must know in order to live intelligently. Since good health depends in a great measure on water, air, food and shelter, we next devoted some time to the problems of *Health.*

But man is never satisfied with the mere necessities of life. He seeks comforts and conveniences. And so we studied that wonderful force, *Electricity,* which in fifty years has changed the civilized world. We have had an opportunity to learn about the telegraph and the telephone, the battery and the dynamo, the radio and television.

But there is more in science than inventions. Science has made the world different because it gave man new ideas, new habits and new ways of thinking. We hope, in this book, to introduce you to some of these ideas, habits and ways of thinking.

SOME BIG IDEAS

One point of difference between plants and animals is that animals are much more free to move around. They move themselves from place to place and they move objects which are in their way. In order to escape from an enemy they start from rest and get into motion; in order to catch their prey they cause moving things to stop. In building their homes, they move materials from one place to another; in adapting themselves to land, to water and to air, they develop different ways of moving about.

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2. Body at rest. Force needed to make it move.

Now, whenever the motion of an object is changed, a push or a pull is exerted. This push or pull the scientist calls a *force*. If an object is at rest, a force is needed to start it moving. If an object is moving, a force is needed to slow it down or to stop it. If an object is moving in a certain direction, a force is needed to change that direction. *A force, then, is a push or a pull which can change the motion of a body.*

If this first idea is clear to you, you are ready for the next.

Work is done whenever a body moves. In lifting a book *work* is done. *Work* is done when the wind blows, because air is moving. *Work* is done when a river flows, because water is moving. When a scientist uses the word "work," he has in mind only that which is done when a body moves.

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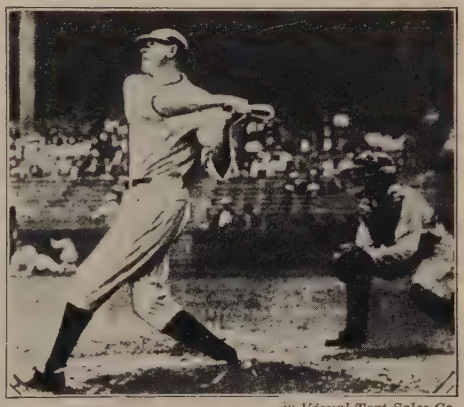
3. Body in motion. Force needed to make it stop.

Of course, we are accustomed to other meanings of the word "work," but we must not confuse these other meanings with the scientific meaning.

Do you do *work* when you are thinking? In the scientific sense of the word, you do *not;* because your thoughts do not move objects outside your body. Do you do *work* when you are straining every muscle to lift a chair that is astened to the floor? According to the scientist you do *not,* no matter how tired you may get. Should you succeed in tearing the chair from its fastenings, you would then be doing *work.*



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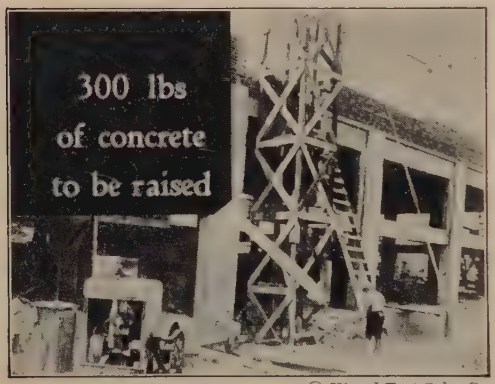
4. Force needed to change the direction of motion of a body.

And now for a third idea.

The ability to do work is called energy. A book on a top shelf possesses *energy;* for it may fall and in falling do *work.* We have already learned how falling water does *work;* and we all know that the wind (moving air) can do *work.* In other words, moving bodies have energy because they can do *work.*

Now, a motionless body can also possess energy because of its position or condition. A stone resting at the top of a hill has more energy than a similar stone at the bottom, for the former can be dislodged so as to roll down. Its position gives it energy. Have you ever shot a bow and arrow? Just before you let fly, you draw back the bow and aim. The arrow is perfectly still; the thong and stick are stretched to the limit. There is energy in the bow, for it is able to do *work,* when you release your hold. In this case the energy is due to the stretched condition of the bow. The same is true of a stretched rubber band and a wound-up clock spring or phonograph motor. They possess energy even when motionless; for they are able to do *work* when released.

At this point, we suggest that you stop reading, in order to think over the three ideas printed in italics above. Do you understand them? Do you understand the examples given to explain them? If you do, you may continue with the few remaining ideas which lead to the first topic presented by this book.



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5. Work done in moving a body against the force of gravity.

KINDS OF ENERGY

1. The wind whipped the ocean into a mad fury. Mountainous waves rose high above the tossing ship and smashed down upon it with terrific force. The tons of steel trembled with each impact and each attack of wind and wave brought the boat nearer to the dangerous shore. The powerful man-made engines could do nothing to combat the fierce energy of the elements. The gigantic steamer, long as the Woolworth building is tall, seemed no more than a piece of driftwood in the grip of the violent sea. The heaving ocean lifted the ship and a second later the fearful crash of steel on rock could be heard above the howl of the wind.

2. In the railroad yards, Number Nine stood hissing and panting. Engineer and fireman were putting finishing touches on the machine which was to pull the Twentieth Century Limited on its long and rapid run. Under the boiler was a raging fire which consumed coal as fast as it could be thrown in. Heat and more heat was needed to boil water into steam, but the steam was not allowed to escape. It crowded into the boiler and the pressure gauge climbed. Fifty! One hundred! Two hundred! The heat of the burning coal kept sending more and more into a vessel already filled. The locomotive did not move. It waited for a hand to operate a throttle. The safety-valve began to tremble, to hiss and to sputter. Were this valve to stick—could the boiler continue much longer to hold out against the pressure and the heat?

3. Ten long subway cars were opened for a rush of passengers who jammed their way into a space seemingly filled with people. When not a single square inch of standing room remained, a man dashed against the mass in the doorway and clung there with all his might. The door would not shut, but the guard, bracing himself against a post, pushed him further into the crowd. The train was ready to start. One minute later the ten heavy steel cars, loaded with humanity, were hurtling through the underground tunnel at fifty miles an hour. The turn of a lever had released energy for this task from an innocent-looking rail by the side of the track,—the "third rail"—dangerous to touch, motionless, but charged with energy that can move tremendous masses at great speeds.

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6. A stretched bow possesses energy.

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7. Heat energy.

4. Do you see this jar of liquid? It looks harmless, does it not? It is hard to believe that there is sufficient energy in this jelly to bring the building down on top of us. They call it nitroglycerine—one of the most violent explosives known. It is a chemical, so unstable that a slight jarring or heating will cause it to break up with terrific force. It stands there motionless and harmless, but in it are great stores of energy—energy that may kill and destroy. Yet, it can be employed by man to do useful work. The energy in explosives is often used to remove obstructions and to prepare the way for foundations.

In each of the four paragraphs above a different form of energy is described. If energy is ability to do work, then there is energy in the waves, in the heated boiler, in the "third rail" and in the nitroglycerine. But scientists have given different names to the forms of energy represented in our descriptions. In the first we have *Mechanical Energy;* in the second, *Heat Energy;* in the third, *Electrical Energy;* and in the fourth, *Chemical Energy.* These are not the only forms we shall study, but we hope you now appreciate the fact that:

There are different kinds of energy—this is the fourth in our list of important ideas.

ENERGY CHANGES

Lay a piece of lead on a hard board and pound it with a hammer. After a while touch the lead. Why did it get hot? It evidently possesses more heat energy than it did before the pounding. The scientist explains this by saying that the mechanical energy of the moving hammer changed into the heat energy of the lead.

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8. Electrical energy.

Boil some water in a test tube which is tightly corked. When sufficient steam is generated, the cork pops out of the test tube. Can we not say in this case that heat energy has changed into mechanical energy?

If a dynamo is to generate electricity, it must be turned. One must spend mechanical energy in turning, in order to get electrical energy from the dynamo. Here, too, there is a change from one form of energy into another.

When you connect an electric motor with a source of electric current, the motor turns. In this case electrical energy changes into mechanical energy.

A piece of coal burns when raised to its kindling temperature in

air. Burning is a process in which the carbon in the coal and oxygen in the air unite chemically. When the chemical action takes place, that is, when the coal burns, heat energy is released. Chemical energy has changed into heat energy.

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9. Energy of motion changing into heat energy.

The heat set free by the burning coal may then be used to boil water into steam and the steam may operate a steam engine. In the latter case, the heat energy changes into mechanical energy.

If, now, the steam engine should turn a dynamo, the mechanical energy would change into electrical energy.

The resulting electrical energy might be used to charge a storage battery, in which case the electrical energy would change into chemical energy. Or, it might be used to heat an electric iron, and so change into heat energy.

Thus, we have traced a series of energy changes. Chemical energy in a piece of coal changes into heat energy; which, in turn, may change into mechanical energy. The latter may be changed into electrical energy which may itself be changed into chemical energy or into heat energy.

All this leads to the fifth idea; namely,

One form of energy may change or be changed into another.

CONSERVATION OF ENERGY

Here is one more idea—the sixth—which you should not find difficult to understand.

As energy changes from one form to another, we sometimes think that it disappears. Let us suppose that you are playing a game of basketball. You jump, you run, you throw, you dodge and you tackle. For all these acts you need mechanical energy; and when the game is over, you are tired—spent. You are likely to say, "I have used up all my energy."

But where did the energy go? The scientist is ready to grant

that it disappeared from your body, but he insists that the energy exists somewhere else. He believes that your mechanical energy changed into heat energy. The air, the ball, the floor, the basket, your opponent and your own body are hotter after the game than before. The energy has changed its form, but it has not disappeared.

As a matter of fact, where did you get the mechanical energy which you used in playing the game?—probably from the food which you ate. This food, possessing chemical energy, changed into the bodily tissues and muscles that give you your strength. The chemical energy of the food did not disappear—it changed its form. The body did not *create* energy—it helped one form to change into another.

Ever since the world began, so scientists believe, there has been a constant amount of energy in the universe. So far as we know, no one has ever created additional energy, nor has any one caused the slightest amount of it to be destroyed.

A machine that will turn forever without receiving energy from an outside source is believed by scientists to be impossible. Even the earth is slowing up in its movements and may some day come to rest. Should you invent a machine which could turn forever, and by itself do work as it turns, you would revolutionize the laws of science. Hundreds of men have tried to do it and have failed. You, too, would probably fail. Scientists are so certain of this that any one who comes to them with a "perpetual motion" machine is at once suspected of being either ignorant or a faker.

Modern science is based on the idea that

Energy can be neither created nor destroyed.

SUMMARY

For convenience, let us list the six important ideas.

1. A force is a push or a pull which can change the motion of a body.
2. Work is done when a force moves a body.
3. Energy is the ability to do work.
4. There are different forms of energy.
5. One form of energy may change into another.
6. Energy can be neither created nor destroyed.

A FIFTH FORM OF ENERGY

We live on a small planet, called the Earth, which revolves around the sun. The brilliant rays of the sun light up our little world, and give it warmth, so that we may live. Nearly all the energy we have and most of what we use comes from the sun, yet we are about 93 million miles away.

Of the energy which the sun sends out into space, the earth gets only a very small part, but it is enough to make life possible. From rays of sunshine we get our food, for plants will not grow without light. As we have already learned, the coal which moves our trains and the gasoline which moves our automobiles are the remains of "ancient sunshine." The waterfalls which drive our dynamos are constantly replenished with water which the sun has evaporated and which has fallen as rain or snow.

So food, fuel, clothing, shelter and energy are practically all derived from the sun. Now, what form of energy does the sun send us? It is not mechanical energy, nor electrical, nor chemical. Some of it is heat energy, but most of it is another form of energy which we call *light.*

Light is perhaps the most important of all the forms of energy we have mentioned thus far, yet it is the most difficult to understand. No one knows exactly what light is, yet we use it, we change it, we cannot do without it. The sun is like a gigantic broadcasting station which sends light energy out into space. We receive some of it and build our lives with it.

The next six chapters of this book will deal with light energy and how it is used and controlled.

HOW MUCH DO I REMEMBER?

A

Indicate the best answer for each of the following. Write your answers on a sheet of paper so as not to mar the book.

1. Four great necessities of life are
   (a) water. (b) air. (c) heat. (d) health. (e) electricity.
2. Science has given the world
   (a) new inventions and new ways of thinking.
   (b) only new inventions.
   (c) only new ways of thinking.

3. A push or pull which can change the motion of a body is called
   (a) a form of energy. (b) a force. (c) work.
4. Work is done whenever
   (a) a force is exerted. (b) a body moves. (c) energy exists.
5. Work is done when
   (a) a boy pulls at a heavy object without moving it.
   (b) the wind blows.
   (c) water presses against a reservoir wall.
6. A force is exerted but no work is done when
   (a) a boy lifts a book.
   (b) water pressure breaks a reservoir wall.
   (c) a boy pulls at a heavy object without moving it.
7. The ability to do work is called
   (a) heat. (b) electricity. (c) energy.
8. Energy is possessed by
   (a) all moving objects.
   (b) some moving objects.
   (c) no moving objects.
9. Energy is possessed by
   (a) all motionless objects.
   (b) some motionless objects.
   (c) no motionless objects.
10. Energy appears
   (a) always in the same form.
   (b) in different forms and can be changed from one form to another.
   (c) in different forms which cannot be changed.
11. Energy can be
   (a) created or destroyed.
   (b) destroyed but not created.
   (c) created but not destroyed.
   (d) neither created nor destroyed.
12. The total amount of energy in the universe to-day is
   (a) more than
   (b) less than
   (c) the same as

   the energy in the universe when the world began.

B

Fill in each empty space with one of the following words: "mechanical," "heat," "electrical," "chemical," "light." Write your answers on a sheet of paper so as not to mar the book.

1. I pounded a piece of lead and it became hot. ..... energy was changed into ..... energy.
2. When a dynamo is turned it produces electricity. ..... energy is changed into ..... energy.

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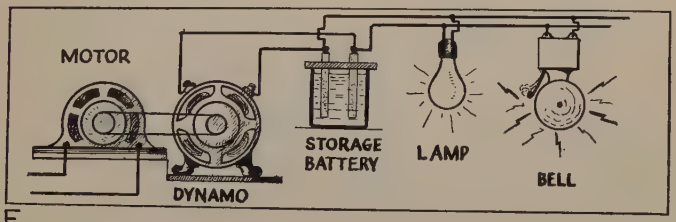
C © Visual Text Sales Co.

D © Visual Text Sales Co.



E

For each of the above tell the following:

1. Are forces acting? Which? 2. Is work being done? How?
3. Which forms of energy are represented?
4. Are there any energy changes? Which?

3. Waves tossed the ship around. The waves possessed ..... energy.
4. The sun sends us ..... and ..... energy.
5. When coal burns, its ..... energy is changed into ..... and light energy.
6. The ..... energy of the locomotive's fire moved the train.
7. When steam pops a cork or moves a train, its ..... energy has been changed into ..... energy.
8. The subway train was moved by ..... energy drawn from the third rail.
9. In an electric motor, ... energy is changed into ..... energy.
10. The ..... energy of the nitroglycerine causes it to break up with terrific force.
11. The ..... energy in the food I eat is changed into ..... and heat energy, when I play.
12. Plants cannot grow without the ..... energy of the sun.

THINGS TO THINK ABOUT AND READ ABOUT

1. Scientists have been thinking for a long time about the ideas which were presented to you in the preceding chapter. Many men of science believe that the amount of energy available for useful work is constantly becoming less and less. What will happen to life when the universe runs down? Where will man get the vast quantities of energy needed to do his work, when existing sources become exhausted? Can we learn to harness forms of energy which have hitherto been unused? Can we use the energy of lightning, of the tides, of the sun's heat, of the millions of tons of waste that we now throw away? The articles listed below are as interesting as their titles, and they give us a partial answer to the above questions.
   "The Eternal Mills of God," Book P, pages 304–312;
   "Life's Ultimate Destiny," Book P, pages 5011–5018;
   "Future Sources of Power," Book O, pages 1971–1988.
2. Here are some shorter references on
   The conservation of energy.
   Book O, pages 1148, 2786–2787; Book P, pages 304, 3601–3611.
   Energy and the sun.
   Book O, pages 394, 1149, 3392; Book P, page 3356.
   Forms and changes in the forms of energy.
   Book O, pages 1211, 2959; Book P, pages 23–23, 303, 305–307, 1982, 1984–1986, 3668, 5016–5017.

CHAPTER I

THE SOURCES AND TRANSMISSION OF LIGHT

On March 14, 1930, the newspapers of our country and of the whole world printed the story of a great scientific discovery. It was thrilling news—eagerly read by the public.

The strange thing about this excitement was that the discovery brought no wealth to any man, nor did it add comforts to our daily life. The interest was due to a message from space. A ray of light, after travelling for 3 billion miles, had reached the earth. Instead of just falling on the ocean or on a tree or on a desert, this particular ray happened to arrive in a little town called Flagstaff in the state of Arizona. Perched on a hill of this town was a dome-shaped building where astronomers lived and worked. In the building was a telescope and into this telescope the ray entered. It passed through the instrument and struck a camera plate. The chemicals on the plate were changed by the ray of light, so that a spot was marked where the light had struck. Later, the plate was studied by astronomers. Their attention was at once attracted to the spot.

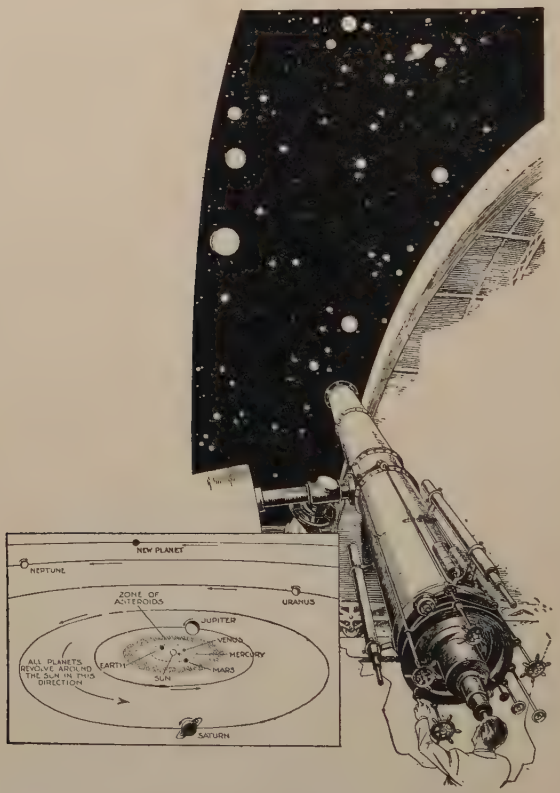
"What is this?" they asked. "Something new? Where did it come from? Is this an accident? An error? Let us try again."

So they aimed the telescope at the region in the sky from which the ray had come, to see if a fresh plate would be affected as was the first. So it was. Night after night they tried it, with the same result. Each night, however, the spot had moved slightly from its position of the night before. The astronomers continued to take pictures of the spot. Two months passed, during which they worked and talked and made calculations. At last they were certain. They flashed this message to Harvard University and from there to the whole world:

"A new planet has been found. There are now nine, not eight planets. The new member of our universe is 3 billion miles away."

An interesting fact about the new planet is that its existence was

predicted at least sixteen years ago. In July, 1914, Professor Lowell finished a series of calculations after years of study. He had come to the conclusion that another planet would some day be



11. A beam of light enters a modern telescope.

found. So certain was he of his results that he made, in effect, this statement:

"The new planet is either 43 or nearly 45 times the earth's distance from the sun. Its trip around the sun takes either 282 years or nearly 300 years. Its mass is 7 or 8 times that of the earth. It will look like a star of the 12th or 13th magnitude. Photograph the region of Delta Geminorum and you will find it beyond the planet Neptune."

Lowell died in 1916, but not before he had succeeded in establishing a world-famous observatory at Flagstaff,—the Lowell observatory, built on top of a hill in the clearest and least troubled atmosphere in the world. Since his death, his assistants have continued to study the planets. And now comes news of a great discovery, which agrees almost exactly with Lowell's predictions.[1]

We have referred to the discovery of a new planet as a "message from space." Astronomers were made aware of the existence of this planet because something from it came to us across 3 billion miles of space. That something was a ray of *light*. But what is light? When light arrives, it seems to be able to do *work*, and so we call it a form of energy. The difficult thing to understand, however, is *how* it travels and what it is while travelling.

To this question scientists have as yet not been able to give a completely satisfying answer. In recent years, certain theories have been found useful in explaining the way light acts and travels. As scientists continue their experimenting and their thinking we shall learn more about the correctness of these theories. Meanwhile, let us perform some experiments of our own and do some thinking ourselves. There is a good deal about light and light energy which is definitely known and accepted by all scientists. This we shall now consider.

1. The sun is the chief source of light

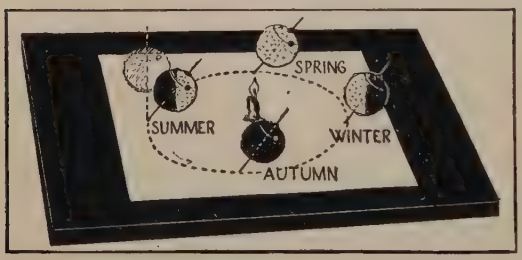
When Rear-Admiral Byrd made his expedition to the South Pole, he went prepared to live through the long antarctic night—a night which lasts for nearly six months. In the winter season, the sun hardly shows its face there. In summer, the sun, barely rising above the horizon, seems to move horizontally and completely around once each day. It does not rise or set for nearly six months. Its slanting rays flood the region with a strange but constant daylight. In this light Byrd did all of the flying and exploring. Though he had electric light, coal and oil, he needed daylight for his important work. The sun was his chief source of light.

[1] There is still considerable discussion among scientists, as to whether the new discovery is a planet. Some think it may be a comet or an asteroid. At any rate, it has been named *Pluto*, God of the distant darkness.

We who live in the temperate zone have days and nights which are shorter, but they come more often. Sunset and sunrise mark the end and the beginning of our workday. Our daily lives are controlled by the light which comes from the sun. Even on a cloudy day, when the sun is not "shining," we get our light from the sun, for up above the clouds the sun *is* shining. Its rays filter through to us from the dust and water particles in the clouds.

We all know that days grow longer as summer approaches, and grow shorter again when winter comes. To understand the reason for this, try the experiment shown in figure 12.

Insert a long needle through an orange. The orange represents the earth, and the needle, the earth's axis. At about the point where your city is located insert a thumb tack. Stand a small lighted candle on the middle of the table. This represents the sun. Draw a circle about one foot in diameter to indicate the path of the earth around the sun. Now, insert the needle vertically into the table at *S* on the circle and rotate the orange. If the room is darkened, you will see that only half the earth is in the light at any one time. Since it takes 24 hours for the earth to make a complete rotation, all points on the earth except the poles will be in the light for 12 hours and in the dark for the remaining 12. Remove the needle and insert it at point *A* or at point *W* or at point *Sp.* You will find that at any point in the earth's path around the sun (which means at any time of the year) the days will be as long as the nights.



12. Why summer days are long.

Now at point *S*, insert the needle at an angle to the table (about 23°). Let the upper end of the needle lean toward the candle. This is approximately the position of the earth's axis during the summer. You will note, as you rotate the orange once, that the thumb tack stays in the light a longer time than it does in the dark. Place the needle at point *W* and with its upper end leaning away

from the candle. This is approximately the position of the earth's axis during the winter season. As you rotate the orange once, and observe the thumb tack, you will find that the latter is in the dark for a longer time than it is in the light. For the spring and autumn observations, place the needle at points *Sp* and *A* respectively, with inclinations of the axis as shown in figure 12.

2. Stars, nebulas, comets and meteors also give some light

On a clear night, when the moon is not visible, one can see many stars and other heavenly bodies. Even with the naked eye, about 4,000 may be seen. Some are bright and some very dim; but if you see a heavenly body, then light must be coming from it to your eyes.

Most of the stars are suns. Many of them are very much larger than our sun, but they are so far away that they seem small. Our own sun has a diameter of 866,000 miles, which is more than 100 times the diameter of the earth, but there are stars with diameters as great as 250 million miles. There are many stars about as large as the sun and many that are smaller, but all of them are so distant, that in comparison the sun's distance from us (93 million miles) is very small indeed.

Among the stars, here and there, one can also find cloud-like masses, more or less circular in shape. When examined with a telescope many of them seem to resemble spirals. These are known as *nebulas* and are believed to consist largely of gases. Close study of the light which comes from nebulas has resulted in some of the most important knowledge of the science of astronomy.

Occasionally, the light from a *comet* is seen on the earth. The name *comet* means *hair* in Greek, for to the ancients these bodies seemed like hairy stars. Long, streaming and luminous tails accompany the central mass of these bodies as they move through the skies. Most comets come near the earth only once. Their paths are such that once having come as near to the earth as they can, they move on never to be seen again. A few comets move in an elliptical path, so that only they can be seen and studied regularly.

Some summer evening, when you can see clearly the thousands of stars in the sky, watch any small area of the heavens for five or ten minutes. If you are patient, you will be rewarded by seeing a shooting star. What you see is not really a star. It is a

meteor—a relatively small mass of matter which is falling to the earth from space. As the mass reaches the air around the earth, the air resists the motion. The speed is very great and so is the friction. Friction produces heat and soon the mass is hot enough to burn—sending out the streak of light which you see. Thousands of meteors fall to the earth in this way, but most of them burn up before they can strike. This is very fortunate for us. Occasionally a meteor is so large that all of it does not burn away. In that case a piece of it may strike the earth as a red hot ball of fire and bury itself deep into the earth. At a museum you may see a number of such meteors[1] which have been discovered and placed on exhibition.

3. The moon gives light by reflection

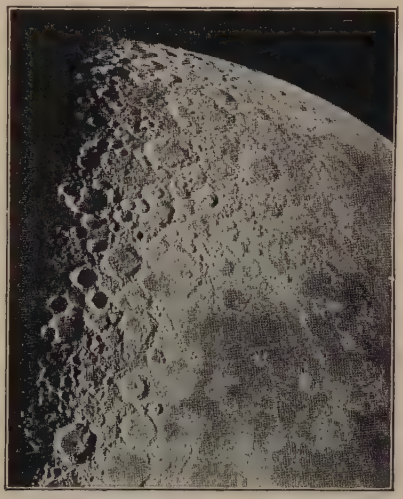
The moon is our nearest neighbor in space. Though it seems to be as large as the sun, the diameter of the moon is only about 2,000 miles. A famous professor of astronomy has said, " If you were to wrap a thread ten times round the equator of the earth, it would be long enough to stretch from the earth to the moon." That would be a distance of about 250,000 miles. No explorer has ever visited our nearest neighbor, yet we know as much about its geography as we do of some parts of the earth. Through telescopes one-half of the moon's surface has been mapped and photographed. Mountains, valleys, craters and canyons have been examined and even named. We know the moon to be cold, bleak and bare, without air or water or life of any form resembling that on earth.

The moon travels in an almost circular path around the earth and makes a complete trip once in about 28 days. Like the earth it spins on its axis, but it makes one rotation in the same time that it takes to move once around the earth, that is, in about 28 days. For this reason, the same side of the moon is always turned toward the earth, and so we really know only one-half of the moon's surface.

Now, we see the moon because its surface reflects sunlight to our eyes. Unlike the sun, it is an illuminated body, rather than a luminous one. Try this experiment:

[1] When part of a meteor has fallen to the earth, it is usually referred to as a *meteorite*.

Hang a ball on a string which is tied to a chandelier. The ball represents the moon. Darken the room. Let your friend shine a flashlight (the sun) so that its light falls squarely on the ball. If you take a position with the "moon" directly between you and the "sun," you will see the black outline of the ball against the flashlight beam. You really do not see the ball, it is sending no light to your eye. The luminous body is the heated filament in the lamp of the flashlight. Now take a position with the "sun" between you and the "moon." You do not see the "sun" at all, but its rays illuminate the "moon." You see the "moon" because it reflects "sunlight" to your eyes; it is an illuminated body. You can easily find a position from which the entire illuminated half of the "moon" is visible. In that case, you see a "full moon." Moving a little to one side, either way, you begin to see less of the bright side of the moon. As you move farther, only a "quarter-moon" is visible. Finally, only a crescent of light can be seen. When you reach the first position, with the dark side of the moon toward you, the "moon" is invisible. This is the "new moon." If you refer to a calendar, you may find the date when the new moon is due. You will not be able to see it on that day, of course, but two or three days later you will find the crescent moon in the western sky.

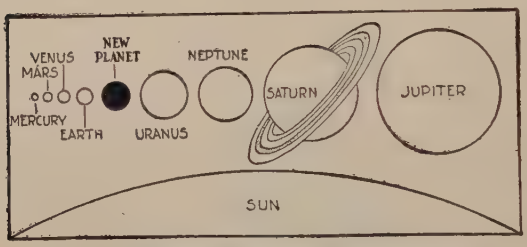


13. Photograph of the moon through a telescope. The moon reflects the light of the sun.

4. Planets also give some light by reflection

Accompanying the earth in its travel around the sun are several other bodies. Some are smaller than the earth and some are larger, some are nearer to the sun and some are farther away,

They are called *planets* or wanderers, and including the earth, they number at least nine large masses. A great many smaller masses, called *planetoids*, have also been observed. The sun and the entire group of planets, together with their moons, are known as the *solar system.*



14. The planets arranged in order of size.

From figure 14 and from the table below, you can learn a great many facts about the solar system.

BODIES	HOW MANY MILLION MILES FROM THE SUN?	THE DIAMETER IN MILES?	HOW LONG TO REVOLVE AROUND SUN?	HOW LONG TO ROTATE ON AXIS?	100 POUNDS ON EARTH EQUALS	HOW MANY MOONS?
Mercury	35	3,000	88 days	88 days?	25 pounds	None
Venus	67	7,700	225 days	225 days?	85 pounds	None
Earth	93	8,000	365¼ days	24 hours	100 pounds	One
Mars	141	4,200	687 days	24½ hours	36 pounds	Two
Planetoids	200–300	20–300	3–7 years	—	—	—
Jupiter	483	85,000	12 years	10 hours	264 pounds	Nine
Saturn	887	70,000	29 years	10¼ hours	117 pounds	Nine
Uranus	1,782	32,000	84 years	?	92 pounds	Four
Neptune	2,792	32,000	165 years	?	112 pounds	One
New Planet	3,000?	?	300 years?	?	?	?
The Moon	93	2,160	365¼ days	28 days	16 pounds	—
The Sun	—	866,000	—	25 days	2,800 pounds	—

As in the case of the moon, we see planets when they reflect sunlight to our eyes. Though not all of them are visible by the naked eye, all of them have been photographed with the light which they reflect into telescopes. The planets most easily and frequently seen with the naked eye are Venus, Jupiter and Mars.

5. Man also obtains light from fires

Though starlight and moonlight and planet-light are all interesting to study and often beautiful to see, man cannot depend upon them for illumination, after the sun has set. When early man discovered fire he used it for light as much as for heat. Fires lit up his cave and helped dispel the gloom of dark nights. The light of fires

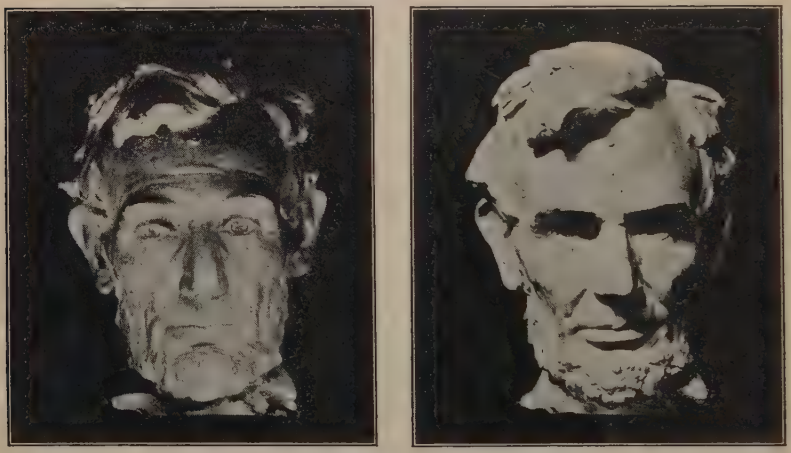
15. Progress in illumination.

played an important part in every phase of his life. As he progressed in civilization he learned new ways of utilizing fire for light. As you can see from a study of figure 15, it is only 40 years or so since fires, in one form or another, were given up as the chief source of artificial light. The modern lamp sends out light from an electrically heated filament. The filament does not burn, and so we cannot use the word " fire " to describe it.

6. Light travels through space at a speed of about 186,000 miles a second

This is a tremendous speed—fast enough to travel seven times around the earth in one second. You may recall that this speed is the same as the speed with which electricity travels through a wire, and radio waves through space.

Perhaps you are wondering how such speeds are measured. We cannot, at this time, undertake to explain the method to you, but we can assure you that the speed of light has been measured in several ways, hundreds of times and by the most accurate scientists. The results agree very closely. Only recently Professor Michelson of Chicago University measured this speed in a series of experiments which lasted several years and cost thousands of dollars. 186,000 miles a second is near enough to his best calculation for us to try to remember it.

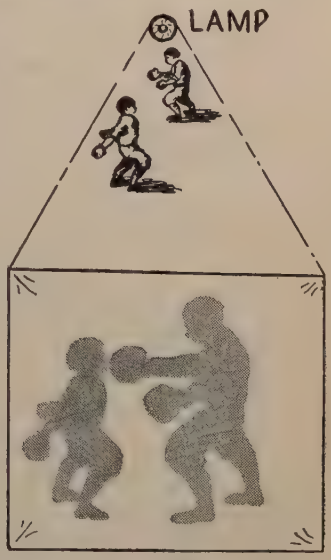


16. Two views of the same statue. Note the differences caused by the different shadows.

You can better appreciate the great speed of light by comparing it with the speed of sound. Did you ever see Babe Ruth swing at a ball so as to hit a home-run? If you are in the grandstand, you hear no sound of bat meeting ball until the latter is sailing through the air. It takes about one second for the sound to reach your ear at a distance of 1,100 feet. The light reaches your eye practically at the same time that Babe swings, for light can travel 1,100 feet in about 1/186th of a second. Similarly, one sees a puff of smoke from a distant locomotive and a second or so later comes the sound of the steam blast. Likewise, a flash of lightning is often seen several seconds before the thunder is heard.

The speed of light has made possible a convenient unit for

measuring great distances, such as the distance between stars. When the astronomer says that a certain heavenly body is 1,000 *light-years* away, he means that a ray of light would take 1,000 years to travel from that body to us. If you wish to know how many miles that would be, calculate the number of seconds in 1,000 years and multiply the result by 186,000. You will find the product to be 5,870,000,000,000,000 miles. There are stars even farther away.



17. Interesting game played with shadows caused by opaque objects.

7. There are bodies which allow light to pass through them, others which do so partially and others which do not let light through at all

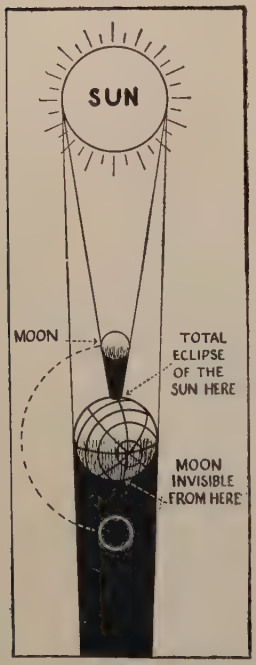
Light travels readily through empty space. It travels almost as readily through air, glass and several other substances. Such substances are called *transparent*, because objects can be clearly seen through them. For example, look through a window pane. You can see objects outside because light from these objects passes readily through air, through the glass, through some more air and finally into your eyes.

If the window pane happens to be made of ground glass much light will enter the room, but not enough to permit objects to be seen through the window. Ground glass is therefore called a *translucent* substance. Tissue paper, thin silk, parchments, frosted glass lamps, oiled paper, etc., are also translucent substances.

Substances through which light cannot pass are called *opaque* bodies. Wood, iron, heavy cloth, etc., are examples of opaque bodies.

If an opaque body is placed in the path of a beam of light, a shadow will be cast. See figure 17. The sharpness of the

shadow depends on whether the beam of light comes from a small source or a large one, and whether the source is a single lamp or several lamps. One reason why we light our homes with many lights placed at different points is to avoid sharp shadows.



18. How an eclipse of the sun and an eclipse of the moon are caused.

Have you ever played the Shadow Game? Hang a curtain as shown in figure 17, place a bright lamp as shown, and then give your performance. You and your friend can make your shadows go through a terrific boxing match without striking each other once in reality. Can you see how this is done?

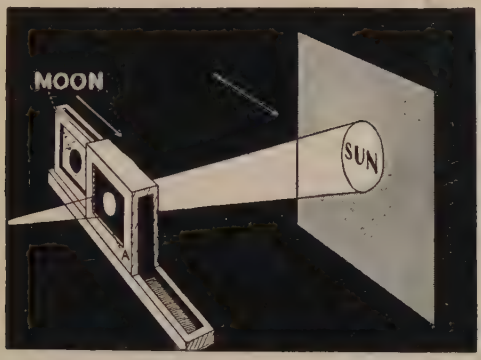
Another interesting example of a shadow cast by an opaque body is an eclipse of the sun or of the moon. In figure 18, you see how the moon may cast a shadow on the earth. If you happen to be where this shadow is cast, no light from the central portion of the sun can reach you, though the outer fringes of the sun (the corona) are visible. This is known as a total eclipse of the sun.

In figure 18, you also see how the earth may cast a shadow on the moon. This is called a total eclipse of the moon.

If your teacher has a projection lantern in your classroom, you can show an interesting experiment which illustrates an eclipse of the sun. See figure 19.

A piece of cardboard, large enough to cover the central opening of the slide-holder, is tacked in place as shown. In the centre of the cardboard, cut a round hole the size of a quarter. When the lantern shines through this hole, a bright circle of light (the sun) is thrown on the screen. Now draw a circle, the exact size of the hole in the cardboard, on a piece of slide glass. This circle represents the moon. Make the circle solidly black with India ink. Place this " moon " slide in the holder and slowly push the latter

into place, as if you were projecting a slide. On the screen you will see a good imitation of an eclipse of the sun.



19. Using a slide-holder to show how an eclipse is caused.

HOW MUCH DO I REMEMBER?

On a sheet of paper, write the numbers of the statements below which are false. Rewrite each of these statements in such a way that it becomes true. You may not do this, however, by adding or omitting the word "not."

1. The ninth planet was discovered when a ray of light entered a telescope.
2. The discovery of the new planet was predicted by Lowell, who studied its light.
3. Light is a form of energy, though it is unable to do work.
4. Our daily lives are controlled by the light which comes from the sun.
5. The long summer and short winter days are due to the inclination of the earth's axis.
6. Most of the light on earth comes from stars, meteors and comets.
7. The light from the moon and the planets is independent of the sun.
8. The stars send us little light because they are far away, not because they are small.
9. Nebulas are believed to consist largely of gases.
10. The diameter of the moon is about 866,000 miles.
11. We know very little about the moon.
12. The same side of the moon always faces the earth.
13. This is because it makes one rotation in the same time that it takes to move around the earth.
14. The moon is an illuminated body, reflecting sunlight to earth.
15. When the side of the moon which is not illuminated by the sun is toward us, we have a "full moon."
16. The solar system consists of the sun, the planetoids and comets.

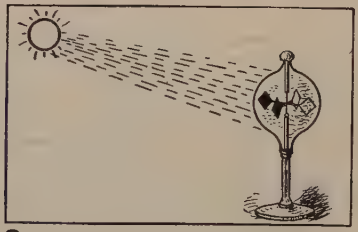
17. The planets most easily seen with the naked eye are Venus, Jupiter and Mars.
18. In an electric lamp, man obtains light from fire.
19. One light-year is the distance which light traverses in one year.
20. It takes practically no time for light to travel from the distant stars to the earth.
21. Substances through which light cannot pass are called opaque bodies.
22. Window glass, ground glass and oiled paper are translucent because they permit light to pass through them only partially.
23. If a transparent body is placed in the path of a beam of light, a shadow is cast.
24. Lighting our homes with many lamps in different places causes sharp shadows.
25. An eclipse of the sun or moon is an example of shadow casting.

THINGS TO THINK ABOUT AND READ ABOUT

1. After learning about the discovery of a ninth planet, you will want to read the following articles:
   "Companions of the Sun," Book P, pages 2711–2718.
   "The Life Story of Worlds," Book P, pages 1429–1436.
   "The Outermost Planets," Book P, pages 3429–3434.
   "The Boundless Universe," Book O, pages 242–247.
   "Children of the Sun," Book O, pages 2815–2819.
2. Not satisfied with being a successful musician, Sir William Herschel set out to become a successful astronomer. He made his own telescopes and with them discovered the planet Uranus. He made many other discoveries in Astronomy and continued his study of the heavens until the ripe age of 83. Read about his life and work in
   Book O, pages 244, 2815, 2818; Book P, pages 3420, 3429.
3. No sooner did Herschel discover Uranus in 1781 than the telescopes all over the world began to follow it on its 81-year journey around the sun. In 1830, rays of light from Uranus were 20 seconds late; in 1840, they were 90 seconds late; in 1846, they were 128 seconds late. "There must be another planet pulling Uranus out of its course," said Adams. Both he and Leverrier calculated exactly where this other planet ought to be. And soon, a powerful telescope, pointing toward the proper place in the skies, received the first messenger from Neptune,—a ray of light. Read more about it in
   Book O, pages 244–247; Book P, pages 728, 3431–3432, 5003.
4. It has been known for a long time that light is an enemy of disease germs. Doctors urge us to play in the sunshine and tell us that homes without sunshine are not healthful places in which to live. Certain ailments can often be cured by sunshine. Children suffering from tuberculosis or from a disease of the bones, known as rickets, are some-

A

B



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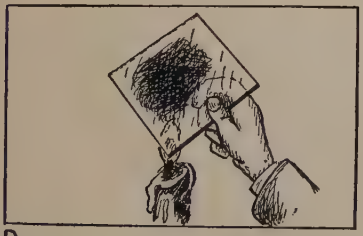

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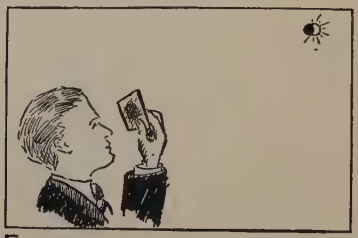


E

A. Athletes in training. Why are they bathing their bodies in light? What kind of light is being used? Why are their eyes protected? B. Certain hospitals treat their patients in this manner. Why? C. Have you ever seen this instrument in an optician's window? Find out why the pin-wheel rotates when the sun shines on it. D. Prepare some smoked glass in the manner shown. E. Use the smoked glass to view an eclipse as shown. Why must an eclipse of the sun be viewed in this way?

times taken for treatment to the top of sunny mountains. There they romp and play, with the sun shining on their naked backs.

Recently, it was discovered that only a part of the energy of sunshine has this beneficial effect on our health. Strangely enough, it is the invisible part of sunshine which our bodies crave. Ultra-violet light, as it is called, cannot be seen and cannot be felt; but it has a profound effect on our lives.

When the air is misty or when clouds cover the sun, most of the ultra-violet light is absorbed or reflected away. Certainly, they are absent at night. Hence, man has learned how to make electric lamps which send out a good deal of ultra-violet light. Also, new kinds of window glass are being manufactured which permits these rays to enter our homes in the daytime, since ordinary glass absorbs them almost entirely. Even certain foods are being exposed to this invisible light; for after exposure, these foods seem to possess characteristics that are essential to good health.

Ultra-violet lamps are recommended by doctors, for healthy people as as well as for sick; but they must be used with the greatest care. Never buy such a lamp without first consulting a physician and never use it unless you are told by him just how much you should expose yourself to the rays. You can find out more about ultra-violet light in
Book O, pages 1998, 3312; Book P, pages 520, 1224, 1785.

5. Eclipses are "shadows in the heavens." They are predicted long in advance by astronomers who know the movements of the sun, the earth, and the moon. Read about eclipses and how to view them through smoked glasses in
Book O, pages 1074–1075, 2318; Book P, pages 2583–2592; Book K, page 181.
6. The Eskimo uses translucent ice to let light into his igloo. The American pioneer made his windows from oiled paper. How much better is the use of transparent glass! Read about the marvels of glass-making in Book P, pages 3981–3996.
7. Sun-dials tell time by the sun's shadow. Find out about this in
Book O, pages 5100–5105; Book P, pages 478, 797, 799; Book K, page 61.
8. Have you ever seen a shadowgraph performance on the stage? Read about it in
Book P, pages 4423, 4429.
9. How far can a powerful searchlight send its rays? How are these powerful lights used in signalling, in lighthouses, on airports? Have you read about recent developments in *noctovision*, the sending of invisible light rays that penetrate the deepest fog and darkness? You will find *noctovision* described in *Popular Science Monthly* for January, 1930. Also read Book O, pages 2003–2006; Book P, pages 3771–3773, 3776, 4685–4704; Book K, pages 229.

10. Albert Michelson, the man who measured the speed of light most accurately.
    Book O, pages 1998; Book P, pages 4342–4343.
11. How were smoke screens used during the war to shut out light coming from warships?
    Book O, page 2424; Book P, page 4855.
12. Some wonders of light. Does gravity pull light? How do nature and man store light energy? Can light energy be changed into sound?
    Book O, pages 2000–2003.
13. If you wish to read an interesting history of lighting, read "From Rushlight to Incandescent Lamp" in "A Popular History of American Invention," Vol. II (Scribner's).

THINGS TO DO AND MAKE

1. To show that light travels in a straight line.
   Book I, pages 9, 17.
2. To obtain a million miles of sunshine.
   Book I, page 5.
3. Experiments with beams of light.
   Book A, page 110; Book F, pages 105–116, 248–263.
4. Experiments with the intensity of light.
   Book I, pages 20–24.
5. Making a photometer to measure the intensity of light.
   Book I, page 23.
6. A pinhole magnifier.
   Book B, pages 191–193.
7. Experiments with making light.
   Book D, pages 110–111.
8. Shadows and shadowgraph entertainments.
   Book D, page 111; Book I, pages 24–28.
9. Flashlight telegraphing.
   Book H, page 155; Book I, page 20.
10. A signalling lamp.
    Book G, pages 415–420.
11. Colored shadows.
    Book C, pages 277–279.

CHAPTER II

THE REFLECTION OF LIGHT

"There is always something new and interesting at Henry's house. The other day I dropped in, and was delighted to find several of my friends, who evidently had also thought of Henry's home as the best place in which to spend a rainy afternoon.

"Henry seemed rather excited. 'Wait till you fellows see what I've got fixed up,' he kept saying. Also, he refused to let us into the room where we usually play. I noticed that the doorway to this room was draped with a velvet curtain.

"After a while, we heard Henry's father from behind the curtain. 'All set, now!' he said, and with that Henry got busy.

"He made us sit in chairs placed directly in front of the draped doorway. Then, clearing his throat and in the manner of a vaudeville performer, he began to speak to his audience.

"'Ladies and Gentlemen: In my recent scientific studies I found a marvellous experiment—an experiment in which objects seem to disappear, in which one person seems to change into another and in which boys and girls seem to change into cats and dogs. Now, this is an intelligent audience and I know you do not believe in the impossible. Neither do I. But sometimes it is difficult to explain the things that happen and the things we see. Science teaches us that there is a cause for every effect. If you can discover the cause of what you are about to see, you are indeed true scientists.'

"Henry now pulled a rope and the curtain was drawn aside. The room into which we looked was very dark, but a doorway directly opposite showed some light through a mosquito netting. Through this netting we could see Henry's sister, sitting on a round stool.

"'Now,' said Henry, 'watch closely! When I say *three*, my sister will disappear into thin air. One — two — three!'

"To our amazement, the girl seemed to vanish, leaving an empty stool. We applauded energetically, but looked at each other in wonder. Henry bowed low and continued.

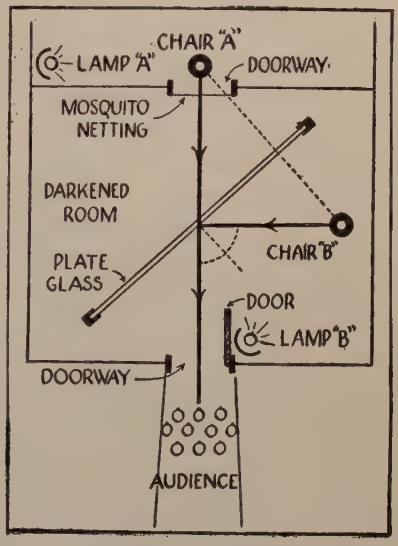
"'Thank you kindly for your applause, but watch what happens next. You all know my dog, Spot. When I whistle, Spot will appear on the chair occupied a moment ago by my sister.'

"The curtains opened and we saw the empty stool, but as Henry whistled, a ghostly shape appeared. Slowly, it became more and more distinct. Finally, there could be no doubt that this was Henry's dog, for he barked and jumped off the stool.

"Chuckling to himself, Henry resumed his speech.

"'One more performance, gentlemen, and then we shall see what you make of it. Look! Do you see my dog? He is on the stool once more. When I wave this stick, watch him change into Toby, our cat; and since you must be worried as to where my sister is, watch the cat change into my sister.'

"'Swish,' went the stick. Again, the dog seemed to vanish, and in his place appeared a cat. A minute later, the body of the cat grew hazy in appearance and at the same time a ghostly image of Henry's sister began to appear. As the cat disappeared altogether the young lady became clearly visible. She stood up, smiled, and bowed to our applause.



21. How Henry entertained his friends with reflected rays of light.

"'Well, what do you think?' cried Henry. 'Have you an explanation?'

"We were all too thrilled with the show to think clearly. The suggestions we offered were laughed at by Henry, but when he tried to explain it to us, he succeeded in confusing us all the more. Finally, Henry's father joined us, very much amused at our conversation, and offered to clear up the mystery.

"He began by taking us into the room. When he turned on the light we saw, for the first time, a large plate glass standing vertically

and at an angle of 45° to the doorway. (See figure 21.) Henry explained that the glass was the table cover from the large dining-room table. Behind the door, to the right of the doorway, we found an electric lamp and a round stool. Behind the mosquito netting in the room adjoining the one in which we now were, we discovered another stool exactly like the first, and to its left there was a second lamp, fixed so that the light could fall on the stool. (See figure 21.)

" ' Now,' said Henry's father, ' let us sit down and examine this drawing of the two rooms. When you first saw Mary, she was sitting on Chair A, illuminated by Lamp A. Lamp B was dark. Her body reflected the light to your eyes through the plate glass, which is transparent. When Henry gave the signal, I merely turned out Lamp A and turned on Lamp B. You no longer saw Mary because no light from her body reached your eyes. The light which did reach you was from the illuminated and empty Chair B. These rays struck the plate glass (which acted like a mirror) and bounced off to travel to your eyes. You were therefore seeing an image in the mirror of the empty chair B. By placing Chair B properly, its image seemed to be exactly where Chair A actually was.'

" ' I next put Spot on Chair A and switched from Lamp B to Lamp A. Again you saw Chair A with its new occupant. While you were wondering at this, I put Toby on Chair B and switched lamps again. This, to your eyes, made Toby appear and Spot disappear. Mary then resumed her place on Chair A. I changed slowly from Lamp B to Lamp A, using a dimmer. You no doubt remember that this caused Toby to become fainter and fainter as Mary became more visible.'

" We played all afternoon with the plate glass mirror, experimenting with it in all sorts of ways. When Henry's father saw that we understood how it worked, he suggested that we try a famous magician's trick of causing a body to seem to rise in the air. He showed us a plan (see figure 22) of how it is sometimes done in the theatre. If we can only secure a large enough plate glass and support it as shown, we are sure to succeed. One of us can stretch out in position A without being seen by the audience. The latter will see an image of a person standing on his head on a table. Then

some one will drag the body slowly along the floor to position B, whereupon the audience will see the image slowly rising into the air.

1. We see an object when light from that object enters our eyes

It is true that " your eyes may deceive you," but it is also true that your eyes will not *see* unless light comes to them. No animal can see in the dark, if the darkness is perfect, though there are some

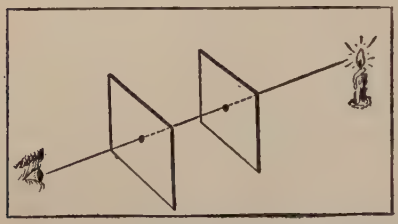
22. How stage illusions may be caused with reflected light.

animals (the cat, the owl) who have eyes that are more sensitive to light than our own and who can therefore see objects from which but small amounts of light come.

When you first enter a motion picture theatre, the hall seems pitch dark, you stumble over chairs and grope your way until an usher comes to your rescue with a flashlight. After you have been seated for a while and your eyes have become accustomed to the dim light you begin to see many objects. You wonder how you could have been so " blind " when you came in. Yet, if all the exit lights, musician lights, and screen light were to be extinguished, you would be able to see nothing, no matter how long you remained in the theatre. Without light there is no vision.

Sometimes a very strong light coming to the eyes makes it difficult, even impossible, to see an object from which only a weak light comes. Thus, we do not see the stars in the daytime—not because they are not shining, but because the sunlight is so much stronger than starlight. It is said that stars can be seen in the

daytime from the bottom of a deep well, since the well shaft excludes a good deal of the strong sunlight. In certain parts of the city, bright electric signs make it almost impossible to view the stars at night. When your teacher shows lantern slides in the classroom, the shades are usually drawn so as to exclude light which is much brighter than the lantern light.

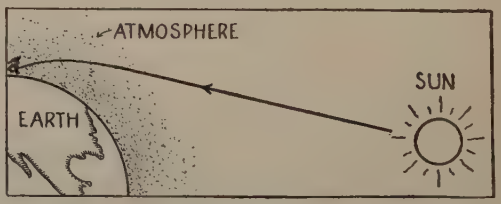


23. Ray of light travelling in a straight line path.

We sometimes read of strange sights on the desert or on the ocean. Parched with thirst, desert travellers suddenly see not far away a cool and shady spring. They rush madly toward it, only to see it move farther away or to vanish completely. Such *mirages*, as they are called, are common experiences, but they do not disprove the idea that light from an object must enter the eyes before the object can be seen. Unless these mirages are mental images caused by a feverish illness of the traveller, the strange visions are caused by rays of light coming from actual objects, far away. They seem near because of a peculiar condition of the air.

2. We see in straight lines

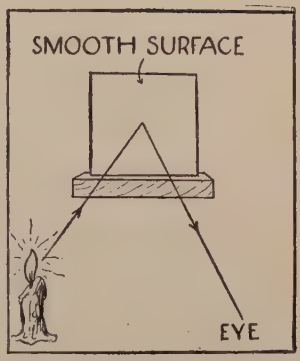
When a ray of light leaves an object, it usually travels in a straight line. See figure 23. However, if the substance through which it travels changes in density, its path may bend or curve. See figure 24. Furthermore, if the ray strikes a smooth surface, the direction of travel may change; though the new path will also be a straight line. See figure 25.



24. Ray of light travelling in a curved path.

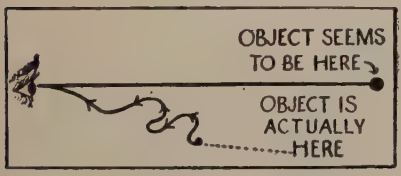
When the eye sees an object, the object seems to be at the end of the ray which it sends out, but to the eye the path seems always to be a single straight line. This is so, no matter how curved or broken is the

path which the light traverses between object and eye. Look at figure 26. Let us suppose that an object is actually at one point and that, for some reason, the light traverses the crooked path as indicated before it enters the eye. The object will be *seen* at a point which is at the end of a straight line, just as long as the crooked line, and in a direction which is the last before entering the eye.

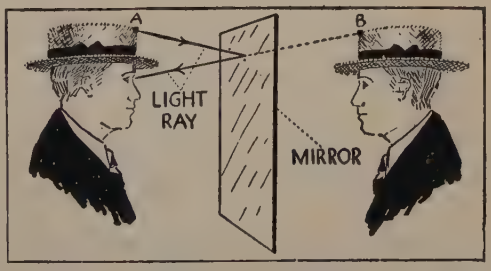


25. Ray of light travelling in a broken path.

As you stand before a mirror, looking at the hat on your head, a ray of light from the hat reaches your eye. See figure 27. The path, however, is a broken one as shown. Nevertheless, the eye sees this path as one straight line. Point *A* of the hat appears to be at point *B* and the whole hat is seen in back of the mirror. You can make this clear to yourself with a hinged carpenter's rule or any two hinged sticks. Hold the rule as shown in figure 28. Each stick indicates a part of the ray's path from hat to mirror to eye. Then swing the upper end around until it is in line with the lower end. The furthest end of the now straight rule is where the hat will appear to be in the mirror. Perhaps you can understand from this why the image of an object seems to be as far in back of a plane mirror as the object is in front of it; also, why your image walks toward you as you approach the mirror.



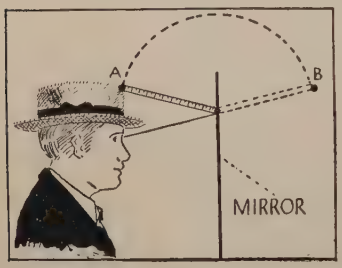
26. "We see in straight lines."



27. How rays travel from object to eye when we look into a mirror.

3. Light is reflected from smooth plane surfaces

We have already mentioned the fact that a ray of light may change its path after striking a smooth surface. That is what happens when light falls on a mirror. In the magical performance described on page 30, the smooth surface of the plate glass changed the direction of travel of the rays of light. The smoother the surface the better is the reflection. Perhaps you have sometimes amused yourself by reflecting sunlight to the ceiling of your room by means of a mirror. (It is of course dangerous to shine the reflected sunbeam into some one's eyes.) You will be interested in trying to reflect sunlight with other smooth surfaces. Try a piece of cardboard, a piece of wood, a handkerchief, a piece of polished metal, a piece of transparent glass, and a piece of frosted glass. Judging by the amount of sunlight you can reflect to the ceiling with each of the above, which material has the smoothest surface? Which has the roughest?



28. An image in a plane mirror is as far in the back of the mirror as the object is in front of the mirror.

The surface of water is often an excellent reflector of light. A glass of water standing in the sunshine is almost as good as a mirror for reflecting the light to the ceiling. As you disturb the glass and roughen the surface of the water, the reflection on the ceiling decreases in brightness. When the surface of a lake or an ocean is calm, the light from the blue sky is sometimes reflected to your eyes. The lake or the ocean then seems blue.

4. The angle of reflection is equal to the angle of incidence (Law of Reflection)

The circles shown in figure 30 represent the pupils seated in a classroom. Fasten a large mirror to the blackboard. With a piece of chalk draw a line on the floor, perpendicular to the front

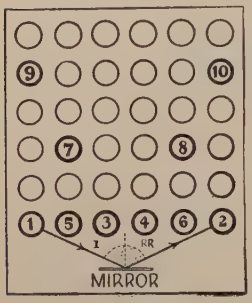
wall at a point directly under the middle of the mirror. Now ask pupil No. 1 to say which of his classmates he sees in the mirror. He will probably see No. 2, who will also see him. Draw chalk lines on the floor from No. 1 and No. 2 to the point where the perpendicular line meets the front wall. Compare the two angles which are shaded in the drawing. See figure 30. Are they about equal? Do the same for pupils 3 and 4, 5 and 6, 7 and 8, 9 and 10, etc.

29. The law of reflection in nature.

When No. 1 sees No. 2, a ray from No. 2 strikes the mirror and is reflected to the eyes of No. 1. In this case, the angle marked *I* is called the *angle of incidence*. The angle marked *R* is called the *angle of reflection*. The two angles are equal.

If you wish to prove this by actual measurement, ask your teacher to show you how angles may be measured with a *protractor*. See figure 31. Then, proceed as follows:

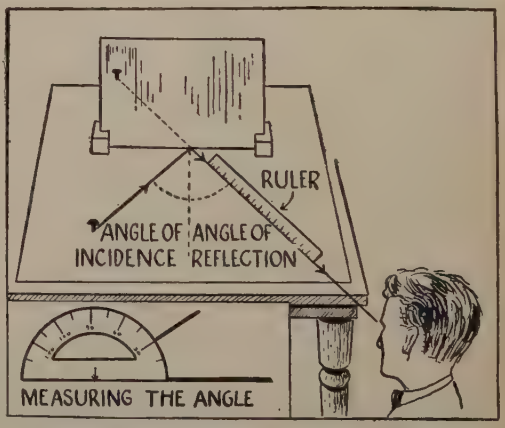
Stand a mirror vertically on a sheet of paper, with its edge resting on a straight line drawn parallel with the upper edge of the paper. Stick a pin anywhere in front of the mirror. Now, aim the edge of a ruler at the image of the pin in the mirror, with your eye close to the table, and draw a pencil line along the ruler. Extend this line until it meets the mirror. At that point, draw a perpendicular line and another line to the pin. The last line is the incident ray and makes an angle of incidence with the perpendicular. The ruler line is the reflected ray and makes an angle of reflection with the perpendicular. Measure the two angles to see if they are equal.



30. How to prove the law of reflection in a classroom.

There are three interesting experiments which you may perform, each utilizing the law of reflection.

The first is to make and use a simple periscope. See figure 38 A. Periscopes, as you know, are used by submerged submarines in watching for enemy battleships. Though such periscopes are more complicated than the one you can make, they illustrate the law of reflection.



31. More accurate proof of the law of reflection.

The second is to make and use a kaleidoscope. See figure 38 B. Into a cardboard mailing-tube insert three long strips of mirror, as shown. Ordinary window glass will do, but mirrors give better results. Lay a piece of ground glass on two wooden supports, so that light can enter through the under side. On top of the ground glass place a few chips of colored glass. Now look down on the chips through the mailing tube.

Each of the three mirrors forms several images of the chips and all the images taken together form a symmetrical design. As you shift the ground glass from its position, this design changes, always giving new and pretty arrangements.

The third experiment is to arrange mirrors in such a way as to give the impression (to some one who does not know about the law of reflection) that you can see through an opaque body. Arrange two boards and three mirrors as shown in figure 38 C. Place yourself at position *A*, so that a ray of light can travel to your eye, as shown. Have your friend hold up an object at *position B*. You cannot see it through the opaque boards, but you can see it quite easily by means of the mirrors.

32. Tall and thin.

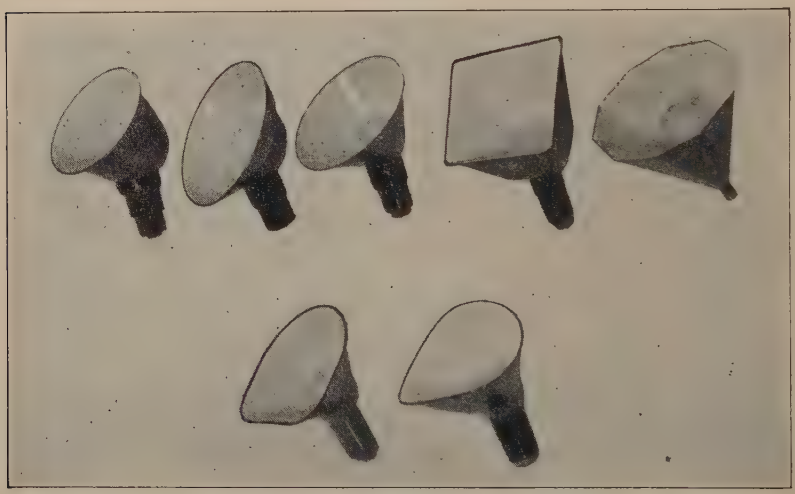
5. Light is reflected from smooth curved surfaces

Look at yourself in the smooth polished surface of a sheet of pliable metal. The image you see is like the one usually formed by a plane mirror. Now, bend it so that the hollow side is away from you, and note how the image changes. By holding this mirror with its straight edge vertical (see figure 32), you will see yourself very tall and thin. By holding this curved mirror with its straight edge horizontal (see figure 33), you will see yourself short and fat. The curved mirror we have just described is part of a cylinder, but such a mirror may also be part of a sphere or part of a surface known as a *paraboloid*. In fact, the shape may take any form that is suitable to a particular purpose. The *concave* or hollowed surfaces of such mirrors are very useful because they can direct a reflected beam of light to a desired place more readily than can a plane mirror.

33. Short and fat.

The outward bulging surface of a smooth curved surface is known as a *convex* mirror.

On this page you see pictures of several different types of concave mirrors. Can you select one which you would use in a home to direct light downward on a reading table? Which would you use to direct light so as to " flood-light " a skyscraper at night? Which might be used in an automobile to direct a parallel beam on the road ahead? The advertising sign reflector? The window-display reflector?

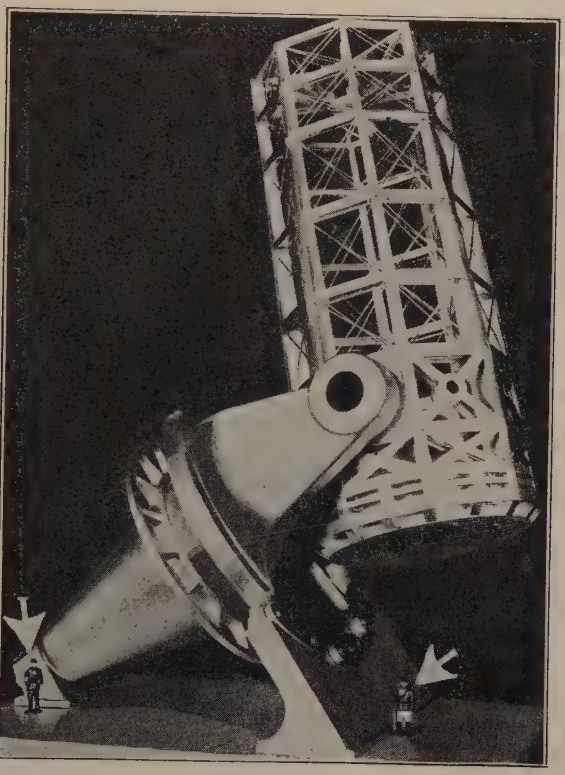


34. Different kinds of concave mirrors.

One of the most important uses to which concave mirrors are put is in the reflecting telescope. At the Mt. Wilson Observatory, a concave mirror 100 inches in diameter gathers the light from a distant star and focuses it on a camera plate. Recently, a 200-inch mirror has been planned. It will take at least 3 years for it to be built, and will cost thousands of dollars, but with it astronomers will be able to see at least four times farther than with the 100-inch mirror. It may help solve many of the mysteries of astronomy, and discover new knowledge about the universe.

For many years men have used concave mirrors in so-called solar engines, that is, they have tried to gather and make use of the large amounts of sunshine which ordinarily go to waste. In one such attempt a tremendous concave mirror focused the sun's

heat on a boiler of water. The water boiled away into steam and the steam drove an engine. As yet these efforts have not been entirely satisfactory.

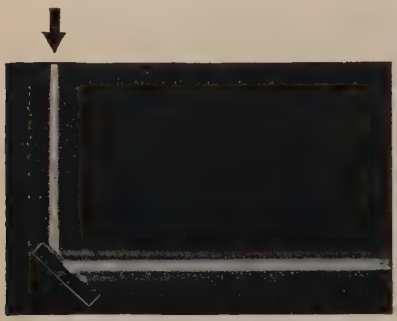


35. Model of the new 200-inch concave mirror telescope.

6. Objects having uneven or rough surfaces are seen by reflected light

Most of the things we see do not have smooth surfaces. When light falls on a rough surface, each part of it reflects the light in a different direction. This results in a diffusion or spread of light at the rough surface. See figure 43. When it is reflecting a beam of light into one's eyes, a surface from which light is diffused can be readily seen. You will recall that in the magical performance

described on page 30, the audience did not see the plate glass mirror at all. They saw, rather, an image which the mirror reflected to their eyes. If a rough surface had been used instead of smooth glass, the surface would have been seen very readily by the light which it would have diffused.



36. Light reflected from a smooth surface.

A simple way to observe the diffusion of light is to draw the shades and shine a flashlight across the room. As a rule, the rays are not visible in the air, but if you stir up dust particles by striking two chalk-erasers together, the beam of light can be seen. The particles of dust in the air act as tiny reflectors, sending rays to your eyes from all directions.

Direct beams of light are very tiring to the eye. Hence, it is the practice to surround the filament of an electric lamp with glass that has been roughened or frosted on the inside. Sometimes the lamp is enclosed in a larger globe of white or "milk" glass. In such case the light is more thoroughly diffused and the illumination is improved.

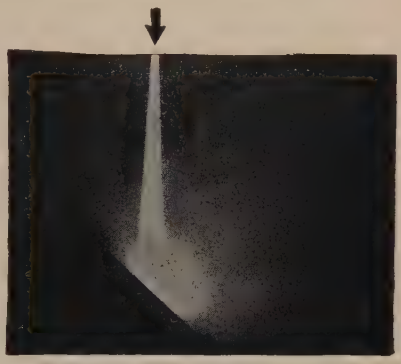
7. Light-colored objects reflect more light than do dark-colored objects

When you enter a darkened room, the only objects at all visible are the light-colored ones. White curtains and walls will be seen, dark furniture and dark-colored rugs will not. Of course, there must be some light present if anything is to be seen, but what little light there is will be more readily reflected to your eyes from the light-colored objects.

Light-colored walls will brighten up a room. The blackboard in your classroom makes the room considerably darker than it would otherwise be, for the boards absorb more light than they reflect. If they were perfectly black, they would reflect no light and would

be invisible. Of course, blackboards can never be perfectly black, especially when they are constantly being covered with layers of white chalk dust.

Examine the ceilings and walls of your home. What color is the ceiling? Is it rough or smooth like glass? Are the walls white? Would white walls reflect too much light? The next time your home is decorated see that the walls are painted a light color, but not pure white, for that would reflect too much light. A "stippled" or roughened surface on the walls also helps to diffuse the light so that no direct and strong beams can enter your eyes.



37. Light reflected from a rough surface.

HOW MUCH DO I REMEMBER?

Write your answers on a sheet of paper so as not to mar the book.

A

1——— 2——— 3——— 4——— 5———

If vaudeville magicians often make things seem to appear and disappear by the use of mirrors, put an I in space 1. If not, put an O.

If vision is impossible without light, put R in space 2. If it is possible for man, put S. If only possible for owls and cats, put T.

If stars cannot be seen in the daytime because they are not there, put U in space 3. If their invisibility is due to the intense light of the sun, put A.

If a ray of light usually travels in a straight line, put G in space 4. If not, put P.

If its path may bend when the substance through which it travels changes its density, put E in space 5. If not, put D.

If you place the proper letter in front of those you now have, you will have a word which appears in this chapter. What does it mean?

B

1——— 2——— 3——— 4——— 5——— 6——— 7——— 8——— 9———

If the path of a ray of light is always seen by the eye as a straight line, put P in space 1. If this is not so, put R.

If the image seems to be on the mirror, put A in space 2. If it seems to be as far in back of the mirror as the object is in front, put R.

If light is reflected from smooth, plane surfaces, put O in space 3. Otherwise, put D.

If the light becomes more diffused when the surface from which it is reflected is made smoother, put S in space 4. Otherwise, put T.

If water is a good reflector when its surface is smooth, put A in space 5. If not, put I.

If the angle of reflection equals the angle of incidence, put C in space 6. If not, put D.

If the reflected ray makes an angle of incidence with the perpendicular to the mirror, put S in space 7. Otherwise, put T.

If periscopes illustrate the law of reflection, put O in space 8. If not, put U.

If the kaleidoscope gives the impression that you can see through an opaque body, put T in space 9. Otherwise, put R.

By inserting a certain letter into the proper place, you will have the name of an instrument. What does this instrument measure?

C

1—— 2—— 3—— 4——5 —— 6—— 7—— 8—— 9—— 10——

If a distorted image is produced in a curved mirror, put P in space 1. If not, put F.

If the outward bulging surface of a smooth curved surface is known as a concave mirror, put I in spaces 2 and 4. If not, leave these spaces blank.

If curved mirrors are used as reflectors, put D in space 3. If they are always used to see images, put L.

If convex mirrors are used in telescopes, put C in space 5. If concave mirrors are used, put B. If mirrors are never used, put D.

If concave mirrors are used in solar engines, put A in space 6. If not, put O.

If objects having rough surfaces are seen by reflected light, put L in space 7. Otherwise, put M.

If the purpose of frosted lamps is to diffuse light, put O in space 8. Otherwise, put I.

If direct beams of light are very good for the eye, put C in space 9. If they are very tiring to the eye, put I.

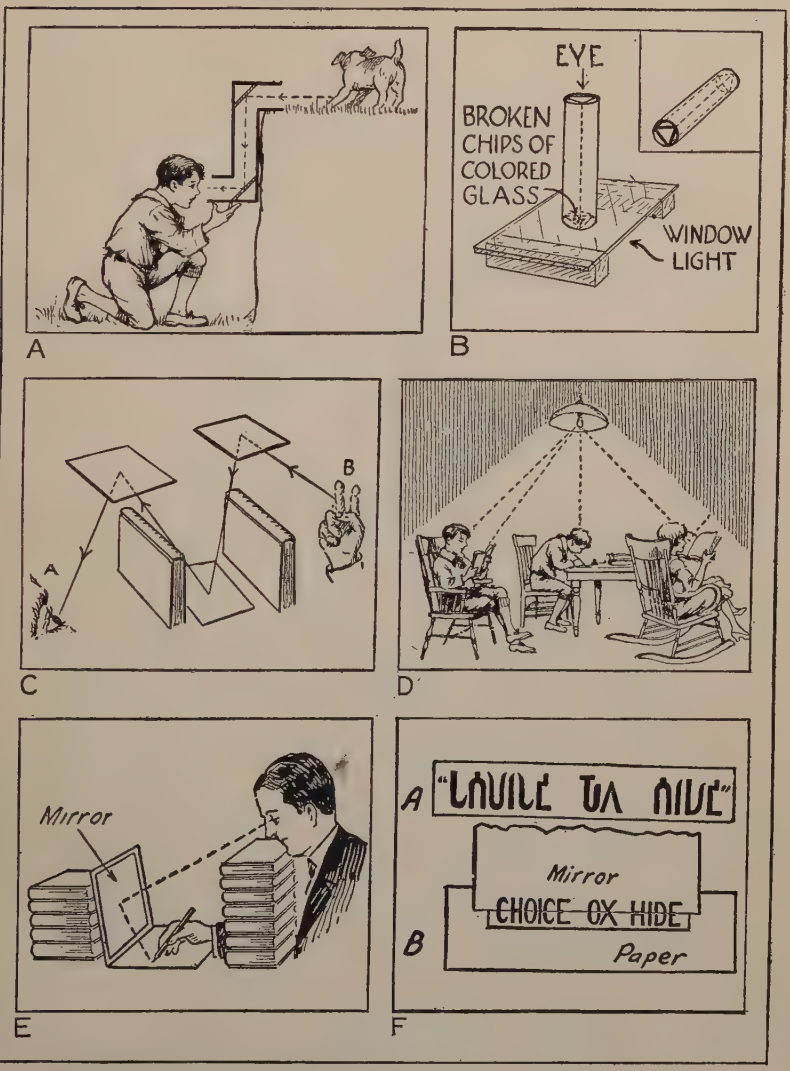
If smooth walls help to diffuse light, put S in space 10. If stippled walls do so, put D. If neither, put T.

If dark objects reflect more light than do light-colored objects, fill blank spaces with E. If the opposite is true, fill blank spaces with the letter that you put into space 6.

By changing one letter, you will have the name of the type of surface used as a reflector for automobile headlights.

THINGS TO THINK ABOUT AND READ ABOUT

1. Thirsty travellers on the burning desert are frequently elated by the sight of a nearby oasis, only to find, on approaching, that what they had seen was a *mirage*. The air above the hot sand is heated; but



A. Make this simple periscope.
B. Can you make this kaleidoscope? You will enjoy looking into it.
C. Try this game. Your friends should not see the mirrors.
D. Which reading position is best? Which is worst?
E. Can you learn to write your name so that it reads correctly in a mirror? Try it, as shown in this drawing.
F. The writing in strip "A" means nothing; but stand a mirror on it as shown — and what do you read?

higher up are cool and denser layers of air. Light coming from a real oasis, which is far below the horizon of the traveller, may, on striking such a layer of dense air, be reflected to the eyes of the traveller. He sees the path of the light as a straight line, and hence the illusion. Mirages are often seen on the ocean. It is told that an English fleet of 19 ships was once seen floating in the air about 30 miles away. Read about mirages in
Book O, pages 2260–2261.

2. Having read about discoveries in astronomy, you will, of course, want to know more about the telescope which made the discoveries possible. The reflecting telescope collects the rays of light from the skies with a concave mirror. The mirror at the Mt. Wilson Observatory is 60 inches wide and is perfect in shape and smoothness. At present a telescopic mirror, 200 inches wide, is being planned. The mirror is at the end of the long tube of the telescope and the image is reflected to another mirror in which the astronomer can observe. Read
Book O, pages 3462–3463; Book P, pages 2114, 5169.
3. How is it that we have some daylight in the morning, before the sun has risen, and in the evening, after it has set below the horizon? The light of dawn and of twilight is produced by millions of dust particles in the upper layers of the air, which reflect to us the light of the sun. In fact, it is the dust which diffuses sunlight, so that objects are illuminated upon which the sun is not shining directly. Far above the earth, where there is no dust, it is utterly dark everywhere, unless you look directly at the sun or at some surface which is reflecting the sunlight. Read
Book O, pages 52, 3570; Book P, page 1798.
4. Mirror Lake—a beautiful picture—illustrating how well water can reflect light, when the surface is perfectly smooth. Read about it in
Book P, page 3840.
5. Illusions and parlor tricks with mirrors. Read about them in
Book O, pages 1717, 2121.
6. The heliograph—a sunlight reflector used in signalling. Find out how it is used in
Book O, pages 3233, 3454, 3455.

THINGS TO DO AND MAKE

1. Simple experiments with the reflection of light.
Book A, pages 112–113, 116–119; Book D, pages 114–119; Book I, pages 28–31.
2. Experiments with one or two plane mirrors and with curved mirrors.
Book B, pages 197–212; Book I, pages 32–34, 51–55, 64–72.
3. Experiments with lighting rooms having dark and light-colored walls.
Book A, page 140.
4. To show the effect of dust on light.
Book E, pages 264–265; Book I, pages 7–8.

5. Dancing Jack in the Looking Glass.
   Book F, pages 93–94.
6. Experiments with reversed images and reversed writing.
   Book N, page 392; Book I, pages 34–37.
7. Mirror codes and mirror writing.
   Book B, pages 199–202.
8. Reflection of light from transparent bodies.
   Book C, pages 273–274; Book A, page 139.
9. Making periscopes.
   Book B, pages 204–206; Book D, pages 142–144; Book I, pages 55–59; Book H, page 212.
10. Looking through a brick.
    Book B, pages 207–208; Book D, page 144.
11. An eye in the back of the head.
    Book B, pages 202–204; Book F, pages 95–96.
12. Making a kaleidoscope.
    Book C, pages 275–276; Book I, page 59.
13. A heliograph—to signal with the sun's light.
    Book H, pages 183–185; Book I, page 31.
14. Tracing drawings made easy with a homemade reflectoscope.
    Book B, pages 209–212.
15. The phantom bouquet, the cabinet of Proteus, the Tutankhamen illusion, and other mirror magic.
    Book D, pages 118, 144–149; Book I, pages 37–50, 60–64.
16. Rowing a boat with the aid of a mirror.
    Book H, page 121.
17. Reading pulse beats with the sun's rays.
    Book H, page 128.
18. Shadows with mirrors.
    Book F, pages 97–102.
19. The water telescope—to scan strange sights in river and ocean.
    Book B, pages 193–195.
20. The silvered egg.
    Book C, pages 298–299.

CHAPTER III

THE REFRACTION OF LIGHT

The large clay pot was finished. Weeks of careful mixing and heating had gone into this piece of work. The purest clay had been used, the most skilful workers had been employed.

A derrick lifted the pot and lowered it again over a fire. Into the narrow mouth of the vessel workmen poured measured amounts of several materials. First, there was sand, clean and white. Then came sodium carbonate, a white salt-like substance; also limestone, pure and powdered. Small quantities of other things were added and then the heat of the fire was increased.

The temperature mounted. The contents of the pot began to melt. When a very high temperature was reached, a workman saw to it that the fire did not get colder or warmer. When the materials were a molten mass, constant stirring began. Now and then a large bubble of gas escaped from the hot liquid. Occasional impurities floating to the top were removed. For one whole week this continued, men taking their turn in watching the temperature, stirring the liquid and in removing the surface scum.

At last the master workman announced the liquid ready. Upon his signal, the derrick tilted the pot and the dazzling, fiery contents flowed out into an iron mould lined with sand. Quickly the mould was covered and slid into another furnace.

An entire month passed by. Each day the fire in the furnace was somewhat reduced. The molten mass cooled slowly, until it reached the ordinary temperature of the air.

When the mould was opened, a large and solid mass was found. It was cleaned and polished. Several inspectors came with cameras, microscopes and other instruments. Every part was examined, several pictures were taken. Apparently, the results were not satisfactory, for the mass was returned to the furnace.

Twenty times was the process repeated. Two years went by before a satisfactory result was obtained. The perfect mass was then cemented to an iron plate. On the upper surface emery

powder was scattered, and on top of this was placed another iron plate which was pushed back and forth by a machine. The surface was ground until it assumed a rounded shape. Measurements were frequently taken as the work proceeded slowly and steadily. A final polishing with cloth and rouge made the mass glisten. The task was finished!

We doubt if you can guess what the rounded *mass* was or the purpose for which it was made, at such a great expenditure of time and effort. We must tell you, therefore, that this work was done at a Paris glassworks, where a *lens* was manufactured for a telescope in the Lick Observatory.

Since the earliest time of recorded history man has known how to make glass. In the beginning he used glass for ornaments. Later, he learned how to blow glass into vessels of various kinds. The Greeks and the Romans knew how to use rounded pieces of glass for "burning glasses," for we read of how they kindled fires with such glass held in the path of the sun's rays. It was not until the year 1300 that it was discovered that the magnifying power of rounded glass could help the eye to see. "Spectacles" came into use at about this time.

Three centuries passed, during which time this use of rounded pieces of glass became common in most parts of the civilized world. Then came a discovery in the shop of a Dutch spectacle maker. Some say this man was Janssen and others say it was Lippershey. The most interesting version of the story, however, is that a young apprentice employed by Lippershey put together two spectacle glasses in a long tube and with this he amused himself by looking at a distant church spire. The weathercock on the spire appeared larger than when seen with the naked eye, and upside down. Lippershey kept this interesting tube to attract customers. Once, an Italian gentleman, Spinola, came in for a new pair of spectacles and became greatly interested in the strange tube. He bought it for Prince Maurice of Nassau, who later used it in warfare to spy upon the enemy. In those days there were few things more important than war, and so the story of the remarkable spy-glass spread everywhere.

Galileo, one of the world's first great men of science, soon learned of Lippershey's spy-glass and began experiments of his own with it.

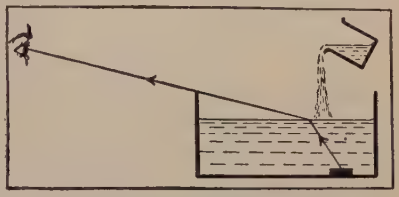
Before long, he had improved on it to such an extent that his spy-glass could magnify objects to three times their size as seen with the naked eye, and without turning the image upside down. Continuing his work, he finally made a tube which could magnify distant objects thirty times. Galileo became famous as the inventor of the world's first real telescope.

The first use to which Galileo put his telescope was to study the moon. He was amazed to discover that the moon's surface was rough and not smooth as every one believed. Upon examining other parts of the heavens, he found that he could count ten times as many stars as could be seen with ordinary vision. Through his telescope, the Milky Way became a mass of separate stars, rather than the glowing cloud which the ancients thought it to be. His most thrilling discovery, however, was that of the four moons of the planet Jupiter. His telescope became popular, and though he had difficulty in convincing the philosophers of his time that his instruments told the truth, his work laid the foundations for the modern science of astronomy.

Now, you will note that the telescope accomplishes its results with rounded pieces of glass, called *lenses*. Lenses have become very important in our lives. In addition to the service which they render astronomers, they are used to correct defective vision, to take pictures, and to project moving pictures on the screen. Scientists use lenses in many of their instruments. In the microscope, lenses magnify tiny objects so that they may be carefully studied. Doctors have learned to combat many diseases with knowledge gained from such study. Lenses are used in numerous other ways. Automobile headlights make use of lenses. The flashlight sends out its rays through a lens. We read small print through a " reading-glass " lens. With a small magnifying lens we examine the warp and woof of fabrics. In the theatre we look at the actors on the stage through an opera glass, which is very much like Galileo's telescope. In short, lenses are so helpful and often create such remarkable effects that we should try to understand how they operate. Let us therefore consider several simple but important ideas. They will help us to appreciate the usefulness of rounded pieces of glass.

1. Rays of light are bent when they pass obliquely from one transparent substance into another

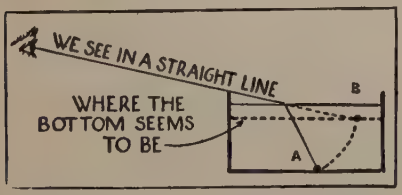
Have you ever looked at a spoon partly immersed in a glass of tea? It seems bent at the surface of the liquid though we know the spoon is perfectly straight. As you put your arm or your leg into a bathtub of water the same apparent break occurs at the surface. Perhaps, too, you have noticed how difficult it is to gauge the position of a piece of soap lying on the bottom of a tub of water. The only time you can put your hands on it without fumbling is when your eyes are directly over the soap, so that you are looking down in a direction perpendicular to the surface of the water.



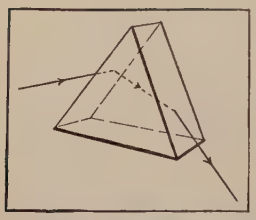
39. An inch or two of water brings the coin into view.

These strange effects are explained by the fact that rays of light change their direction of travel when they pass from one transparent substance into another. The following experiment will illustrate the idea:

Place a coin at the bottom of an empty jar. Shut one eye and look at the coin obliquely across the upper rim of the jar. Lower your open eye until the side of the jar just hides the coin from sight. As you keep your position fixed, have a friend pour water into the jar. See figure 39. An inch or two of water brings the coin into view. Now, since we never see an object unless light from that object reaches the eye (see page 33), the coin must be sending a ray of light to the eye. This ray could not have travelled in a straight line, because a straight line between coin and eye is intercepted by the side of the jar. Therefore the ray must have bent somewhere in its path so as to reach the eye and avoid the side of the jar. From other experiments, we



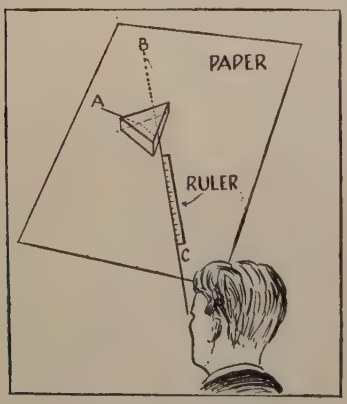
40. Why the bottom seems raised.



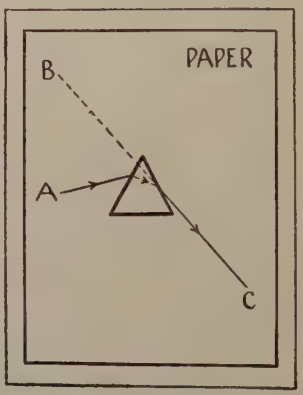
41. Ray of light passing through a glass prism.

know that this bending takes place at the surface of the water. It is there that the ray passes from water into air.

You will note in this experiment that the entire bottom of the jar seems to rise when looked at obliquely, so that the depth of water seems less than it really is. To understand this, read again page 35. There you learn that when we see an object, the object seems to be at the end of the ray which it sends out, but that to the eye this ray seems always to be a single straight line. In figure 40, you see the actual path traversed by a ray from a point *A* on the bottom of the jar to the eye. This is a broken path. However, the eye sees this path as a single straight line. Hence, point *A* will appear to be at point *B*—similarly with every other point of the jar bottom, so that the entire bottom seems to rise when looked at obliquely through water.



42. Sighting for a pencil line through a glass prism.

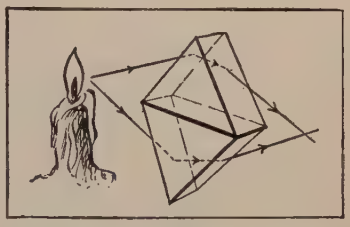


43. A prism bends a ray of light toward the base.

The bending of a ray of light as it passes *obliquely* from one transparent substance into another is called *refraction*. There is no refraction when a ray enters a transparent substance perpendicularly. When one looks directly down at an object under water, the position of the object can be gauged correctly.

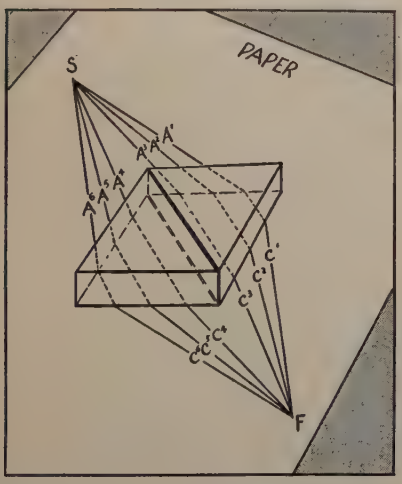
2. Light going through and out of a glass prism is bent toward the base

A glass prism is usually a five-sided piece of glass with two sides parallel to each other and the other three at an angle to each other. See figure 41. When a ray passes into a glass prism, it is bent. Upon passing out of the prism, it is bent again. The direction of the ray when it comes out is closer towards the base on which the prism stands. See figure 41. Try this experiment:



44. Two prisms placed as shown, can bend rays of light upward and downward.

Draw a pencil line, *A*, on a sheet of paper. See figure 42. Place a glass prism on the paper so that line *A* meets at an angle one of the edges of the prism. Sighting along the edge of a ruler, with your eye at the table level, aim the ruler at line *A* as seen through the prism. Line *A* will appear to be at *B*. When you have adjusted the edge of the ruler so that it is in line with the line you see, draw a pencil along the ruler so as to get line *C*. Trace the outline of the prism on the paper, then remove the prism. Figure 43 shows the result. Do this experiment several times, with line *A* and the prism in different positions. The result will always show that a prism bends a ray of light towards the base.

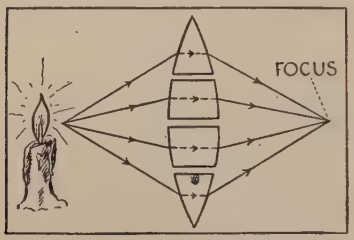


45. Sighting for pencil lines through two prisms placed base to base.

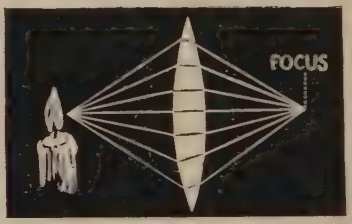
3. The convex lens bends rays of light somewhat as do two prisms placed base to base

If two prisms are placed base to base, the upper one bends rays downward; the

lower one, upward. See figure 44. You can sight for the bent rays with a ruler by arranging two prisms on a sheet of paper as shown in figure 45. Proceed as before, and you will find that C_1 is the direction of ray A_1 after passing through the upper prism.



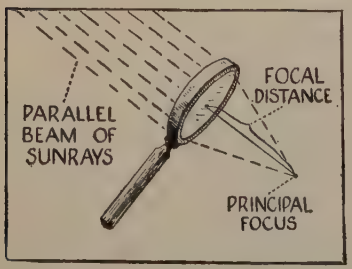
46. A convex lens acts like a series of prisms.



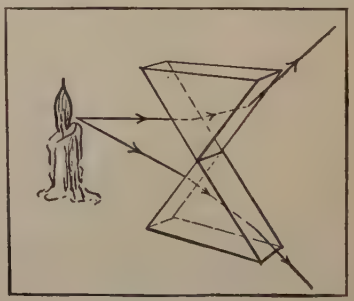
47. Bending rays to a focus.

Similarly, C_2 is the direction of A_2 when it comes out, C_3 is A_3, C_4 is A_4, C_5 is A_5 and C_6 is A_6. If all the rays on one side of the prisms start out from one point, S, they all meet at point F on the other side of the prisms. Point F may be called the *focus* of all the rays.

Now, a lens may be considered as being made up of a great many prisms, placed as shown in figure 46. All the upper prisms bend rays downward and all the lower prisms bend rays upward. A real lens has spherical surfaces, but the action on rays of light is the



48. Focusing a parallel beam of light.

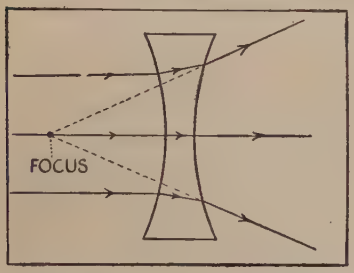


49. Two prisms placed point to point.

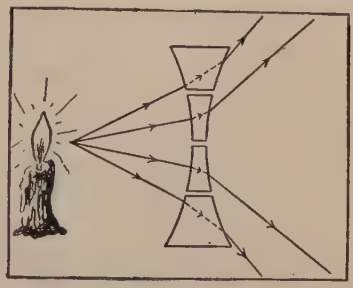
same. Rays starting from a candle strike a lens and are bent so that they meet at a point called the *focus*. See figure 47.

If a lens is held in the path of a beam of parallel rays, as in rays coming from the sun, the rays are focused at a point, and the resulting concentration of heat may set fire to an object placed at that

point. Such a focus is known as the *principal focus* of a lens and the distance between it and the centre of the lens is called the *focal distance*. See figure 48. Perhaps you have already observed that



50. The "focus" in a concave lens.

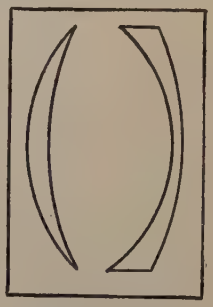


51. A concave lens also acts like a series of prisms.

the focal distance depends on the curvature of the lens. A lens that bulges outward a good deal has a short focal distance; that is, the principal focus is very close to the lens itself. A lens that bulges outward but little has a long focal distance; that is, the principal focus is far from the lens itself.

4. The concave lens bends rays of light somewhat as do two prisms placed corner to corner

By arranging two prisms as shown in figure 49, you can sight again with a rule to determine the directions in which rays come out after passing through the prisms. You will find that with this arrangement of prisms the rays again come out bent toward the bases, but since the bases are not together, the rays spread out. They do not focus.



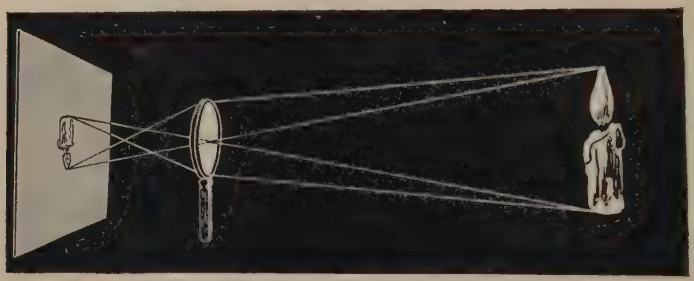
52. How some eyeglass lenses curve.

A concave lens may be considered as being made up of a great many prisms placed as shown in figure 51. The focal distance of such a lens must be determined in a special way, since the rays do not focus. In figure 50 we have extended backward the rays which come out of the lens. The distance between the point where these extended rays cross and the centre of the lens is the focal distance.

If you examine an eye-glass, you may find that one surface bulges outward (is convex) and the other surface bulges inward (is concave). How can one decide whether the eye-glass is convex or concave? The way to tell is to see whether the middle of the eye-glass is thicker or thinner than the outer edge. See figure 52. If the middle is thicker, the lens acts like a convex lens; if it is thinner, it acts like a concave lens.

5. Light from a distant object may be bent by a convex lens so as to focus a small inverted image on a screen

As we have already seen, light from the sun is bent by a convex lens so that the rays come together at a point. This point, when examined carefully, is found to be not a point, but a small circle.



53. Forming a small inverted image.

This circle is really an image of the sun. With objects not so far away as the sun, it is possible to focus images that can be recognized more easily. Do this experiment:

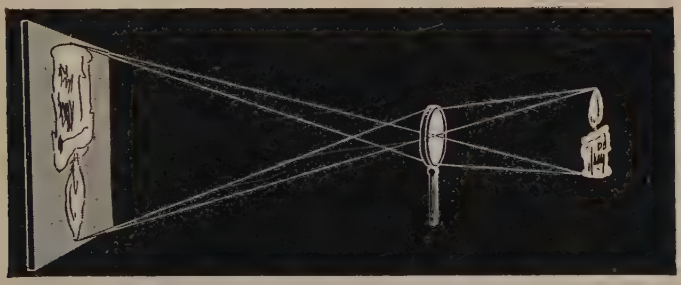
Stand a lighted candle on the table. Draw the shades so that the room is somewhat darkened. About three feet from the candle support a sheet of cardboard, which will serve as a screen. Hold a magnifying glass (double-convex lens) near the screen, in the path of the candle rays, and move the lens slowly toward the candle. Stop moving the lens when a sharp image of the candle is visible on the screen. See figure 53. The image is smaller than the candle itself, and is inverted. The inversion is due to the fact that the rays coming from the top part of the candle cross those coming from the bottom of the candle. The size of the image depends on how far away from the lens you place the candle. The farther

away the object is from the lens, the smaller is its image when focused. That is why an image of the sun, which is 93 million miles away, is so small as to seem practically a point.

In a camera, the lens acts like a double convex lens. The object whose picture is taken is usually six or more feet away from the lens. Hence the image focused on the film is small and inverted. The more distant the object the smaller is its picture (image) when focused.

6. Light from an object at a certain short distance from a convex lens may be bent so as to focus a large inverted image on a screen

From the experiment performed above, we saw that the image of the candle when focused on the screen (see figure 53) is larger when the lens is nearer the candle. Positions for the lens and for the



54. Forming a large inverted image.

candle may be found where the focused image is the same size as the candle. In this case, the lens is just as far from the screen as it is from the candle. If you now move the lens still closer to the candle (see figure 54), you will need to move the screen farther away in order to focus the image on it. The image will be larger than the object, and inverted.

It is interesting to notice in this connection that there is a limit to the closeness with which the lens may approach the candle and yet produce a large, inverted image on the screen. This limit is the focal distance of the lens. In order to focus a large, inverted image on the screen, the candle must be more than once the focal distance away from the lens, but less than twice the focal distance.

7. When the eye views an object through a convex lens that is at less than its focal distance from the object an enlarged and upright image is seen

In the previous paragraphs we set a limit to the closeness with which the lens may approach the candle, if an enlarged image is to be focused on the screen. What happens if we step beyond this limit? Try it with the lens, candle and screen described above. Can you get any image on the screen at all? You cannot.

However, if you view the candle through the lens when the latter is at less than its focal distance from the candle, you see an enlarged and upright candle. Look also at your finger or a page of print through a convex lens held at less than its focal distance away. Again you see the finger or the print much enlarged and upright. You are using the lens as a magnifier or as a reading glass. This is the idea on which the simple microscope is based.

SUMMARY

It would be well at this point, if you reviewed the *seven* ideas presented in this chapter:

1. Rays of light may be bent.
2. Rays of light are bent by a prism.
3. Prisms may be used to form a convex lens.
4. Prisms may be used to form a concave lens.
5. Convex lenses are used in telescopes, cameras and the eye.
6. Convex lenses are used in projection lanterns.
7. Convex lenses are used in a microscope.

HOW MUCH DO I REMEMBER?

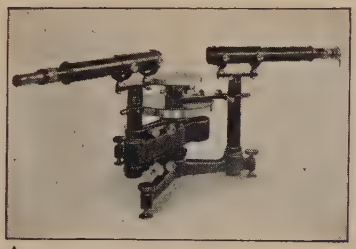
A

Tell whether each of the statements below is true of

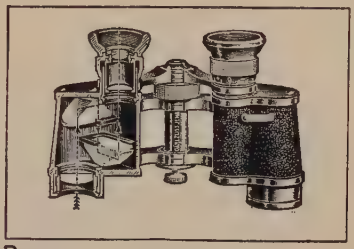
(a) *a convex lens.*
(b) *a concave lens.*
(c) *either a convex or a concave lens.*
(d) *neither a convex nor a concave lens.*

Write your answers on a sheet of paper so as not to mar the book.

1. Is made of glass.
2. Is a burning glass.
3. Is a magnifying or reading glass.

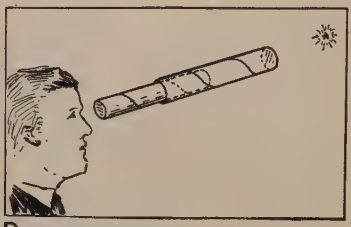


A

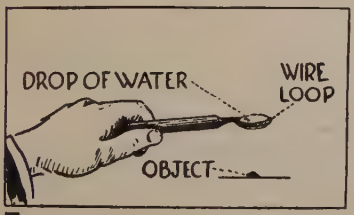


B

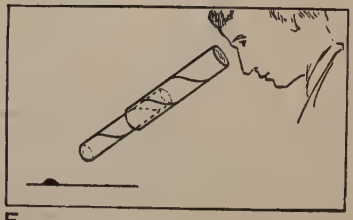
C



D



E



F

G

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A. Find out the name of this instrument and learn its uses.
B. This instrument contains both lenses and prisms. Why?
C. This is a stereoscope. What is its special value?
D. Make this telescope with mailing tubes and small lenses.
E. Try this.
F. Make this microscope.
G. Piece of ice starts a fire. Explain.

4. Bends rays of light.
5. Bends all rays of light downward.
6. Bends all rays upward.
7. Bends some rays upward and some downward, so that they all meet at a point called the focus.
8. Bends all rays outward, thus spreading the beam.
9. Has a spherical surface.
10. Bends rays somewhat as do two prisms placed base to base.
11. Bends rays somewhat as do two prisms placed corner to corner.
12. Has a focal distance.
13. May be made flat or plane on one side.
14. May have both surfaces bulging outward.
15. May have both surfaces bulging inward.
16. May have one surface bulging outward and the other inward.
17. Is thicker in the middle than at the outer edges.
18. Can bend light from a distant object to focus a small, inverted image on a screen.
19. Is used in the camera.
20. Is part of the equipment of the eye.
21. May bend light from an object at a certain distance from it, so as to focus a large, inverted image on a screen.
22. Is used in a projection machine.

B

In List X you will find a word or group of words to correctly fill each empty space. Do all your work on a sheet of paper so as not to mar the book.

1. Glass is made from ....., limestone, sodium carbonate and other chemicals.
2. The greatest care and months of labor are required to make the lens for a .....
3. The spy-glass was invented by .....
4. The world's first real telescope was made by .....
5. The four moons of Jupiter were discovered by .....
6. The science of astronomy was made possible by the invention of .....
7. In ....., lenses magnify tiny objects so that they may be studied.
8. An opera glass is very much like .....
9. ..... of light takes place when a ray passes obliquely from water to air.
10. There is no ..... when a ray enters a transparent substance perpendicularly.
11. Light going through or out of a glass ..... is bent toward the base.
12. The point at which a beam of parallel rays is focused is called .....
13. The distance between the centre of a lens and the principal focus is called the .....
14. A lens that bulges outward only a little has a long .....
15. A concave lens with one flat surface is said to be .....

16. Since the rays coming from the top part of the candle cross those coming from the bottom, after they are bent by the lens, the image is .....
17. In the camera, the image is focused on the .....
18. In the eye, the image is focused on the .....
19. In the projector the slide or film must be more than once but less than twice the ..... away from the lens.
20. If a slide were put into the machine right side up, the image on the screen would be .....

List X

reflection	prism	eyeglasses
sand	Spinola	double-concave
upright	lens	the principal focus
focal distance	the microscope	plano-convex
the retina	clay	a large telescope
Lippershey	refraction	plano-concave
Galileo	the film	the telescope
	inverted	

THINGS TO THINK ABOUT AND READ ABOUT

1. The periscope is the submarine's "roving eye." With it a submerged submarine can look out upon the open sea. When we studied the action of mirrors in Chapter II, we learned that two mirrors may be placed in such positions that objects are seen which are not in direct line of sight. But the periscope which a submarine uses is more elaborate, since it must view large areas in all directions. This is accomplished with specially shaped lenses which reflect light in the manner of mirrors, but which also act like a telescope. Thus, the periscope makes use of both reflection and refraction. Read more about the submarine periscope in Book O, pages 2730, 3376, 3377; Book P, page 4956; Book K, page 13.
2. More about telescopes.
   Book O, pages 239–242, 1391, 2105–2114, 2551–2552, 3462–3463; Book P, pages 18–19, 240, 2963, 3412, 3414, 4648, 5109.
3. The making of lenses.
   Book P, pages 2516–2517, 2659, 3984–3989.
4. More about the microscope.
   Book O, pages 474, 1474, 2228–2230, 2342; Book P, pages 84, 240, 2514–2528.
5. Field glasses, opera glasses and binoculars.
   Book O, page 3463; Book P, page 2112.
6. Have you ever stopped to think of why we have *two* eyes? If we had but one eye, things would seem less real. Looking at an object with one eye would produce an image like a flat picture of the object.

   Each eye produces a separate image on the retina. These images are not exactly the same, for each eye views the object from a slightly different angle. (The eyes are about $3\frac{1}{2}$ inches apart.) However,

the brain sees only *one* image, which is the merged view of both images. This merging of images helps us to see the "depth" of an object as well as its length and width and so it appears more life-like.

There is a device known as a *stereoscope* with which flat pictures can be viewed so that they appear more real. A double picture is inserted into this device. The two pictures have been photographed by two cameras placed as far apart from each other as are the eyes of a human being. The "left" camera has therefore viewed the object as the "left" eye would see it, and the "right" camera as the "right" eye would see it. In the stereoscope the two pictures are seen as one, which is exactly as the two eyes would see the object in reality. Read
Book O, page 3354.

7. We see the sun for some time after it has sunk below the horizon. This may sound impossible, for we have learned that we see in straight lines. Yet, it is so; and for a very interesting reason. When the rays from the sun strike the atmosphere, they bend. Since the air becomes gradually denser as the rays approach the surface of the earth, they bend more and more. The result is that the rays curve up from below the horizon, along the surface of the earth, and to our eyes. If you wish to learn more about this interesting fact and also about why we see the sun before it has really risen above the horizon, read
Book O, pages 52, 1999; Book P, pages 2316, 4992.

THINGS TO DO AND MAKE

1. Experiments with the refraction of light.
   Book A, pages 114, 119–122; Book C, pages 300–302; Book D, pages 119–124; Book E, pages 265–270; Book I, pages 73–86.
2. Experiments with lenses.
   Book B, pages 212–217; Book C, pages 280–282; Book E, pages 270–274; Book I, pages 103–113.
3. Lighting fires with lenses.
   Book A, page 130; Book B, pages 182–184, 186; Book C, pages 283–284.
4. How to make glass lens and water lens magnifiers.
   Book B, page 193; Book D, pages 136–138.
5. How to make a telescope.
   Book D, pages 135–136; Book I, pages 113–116.
6. How to make a spyglass.
   Book B, pages 214–216.
7. Making an opera glass.
   Book I, pages 116–118.
8. Light effects for a show-window.
   Book H, page 52.
9. Newton's rings and the furrowed images. How to demonstrate light interference.
   Book C, pages 306–309.

CHAPTER IV

THE CAMERA AND PHOTOGRAPHY

His wife thought he was going mad. For weeks and months, day and night, he had been fussing with chemicals. His hands, his clothes, the furniture of his workshop, were all stained with acids. In his sleep he spoke of his experiments in a way which frightened his family.

At last, the poor lady went to certain friends of her husband. " I am the wife of Daguerre, the painter," she said. " My husband has been seized with an idea which is ruining his health. He thinks he can make the sunshine paint pictures on chemicals. Since you are men of science, can you tell me, please, if such a thing is possible? "

One of them replied, " Madam, in the present state of knowledge, it cannot be done. But who will say that it will always remain impossible? Be patient, encourage him. Do not set him down as mad."

Fourteen years later occurred a lucky accident which brought success to Daguerre, and with it, the modern age of photography. The modern " movies " and the " talkies " would hardly be possible except for this man's bulldog-like persistence.

Early in the nineteenth century, scientists and artists were interested in the " camera obscura," which is the Italian for dark room. It was the invention of a man named Porta. One could go into such a room and see on the wall, or on a screen, a picture of things outside the room. The image was formed by rays of light passing through a small hole. Artists would draw the pictures they saw and many would come to observe, out of curiosity.

A man named Niepce then discovered that if these pictures were allowed to fall on a metal plate covered with asphalt, and if the exposed plate were then washed with oil of lavender, a permanent picture would be etched on the plate. In 1825, Daguerre became interested in this sort of picture-making. He formed a partner-

ship with Niepce and together they tried many experiments in order to improve the process. Eight years passed without result. Then Niepce died. Daguerre continued by himself.

One day he was trying out a new kind of plate. It was of silver and had been fumed with iodine vapor. He permitted light from an object to fall on the plate; but since the exposure was for too short a time, he could see no result. A little tired and somewhat discouraged, he put it away in a closet where he kept his chemicals. The next morning, upon going to the closet, he was amazed to find a clear picture etched on the same plate which had been blank the day before. What had happened?

56. Daguerre's discovery.

Daguerre was greatly puzzled. Reasoning about it, he decided that something in the closet was responsible. Which of the many chemicals had caused it? Though there were hundreds of bottles he began his patient search. One by one, he took out a chemical at a time, always putting a freshly exposed plate into the closet. The picture formed each time. At last, he reached the very last bottle; and removed that one, too. To his surprise, the picture seemed to form on the plate without any chemical.

He was almost ready to give up in despair when he spied some mercury which had spilled on the floor. Could that be it? Once more he prepared a silver plate and exposed it to light. Into his closet it went, but this time the mercury was gone. Twenty-four hours later he knew the guilty culprit. It was mercury vapor.

Daguerre became famous. People flocked to see him and scientists from all over the world wrote to him about his work. His pictures were very crude and expensive to make; but they

were different from anything known before. These early "tintypes," as they were called (for the pictures were formed on chemicals covering metal plates), were hailed as a means of recording works of art. Soon, however, a greater use for Daguerre's process developed. Men and women in great numbers asked to have their pictures taken, even though they had to cover their faces with white powder and sit in the bright sunshine for half an hour. The age of modern photography had arrived.

But science never stands still. The "tintype" was only ten years old, when Talbot showed how pictures could be made on paper treated with silver salts. He was followed by Herschel, who discovered the use of "hypo," a chemical which fixes the picture on paper. Then Reade found a substitute for mercury vapor; and by 1871, Dr. Maddox had devised a gelatin film which could be coated with silver salts. Many other experimenters had a share in the final product which are now used for taking pictures.

Millions of cameras are sold each year in our country. We produce annually $72,000,000 worth of photographic equipment. The motion picture industry has become one of the largest and most important. Though there has been much progress since Daguerre's time, we are still making use of his idea of letting rays of light paint pictures on chemicals. The first photo took several hours, but we can now take 20,000 pictures in one second.

1. Essential parts of a camera

In the story about Daguerre, we mentioned the "camera obscura" devised by Porta. Not only is the name "camera" derived from Porta's invention, but the idea on which the modern camera is based also goes back to this crude attempt to form images on a screen. Let us examine a camera in order to study its essential parts.

1. The *lens*—the most important and often the most expensive part of a camera. In Chapter III on page 56, you learned how a convex lens may be used to focus on a screen a small inverted image of a distant object. That is the purpose of the lens in a camera.

2. The *screen*—on which the image may be focused. In the camera the *film* or *plate* serves as the screen. As you know, even

twelve films may be inserted, either as a roll or as a pack, and each film used in turn by moving a knob at the side of the camera.

3. The *lightproof box*, which is in fact a small dark room (camera obscura). In the more expensive cameras, the " bellows " makes possible an enlargement of the dark box, which excludes all light except that which comes through the lens. Even a pin-prick in the bellows may let in enough light to spoil the picture.

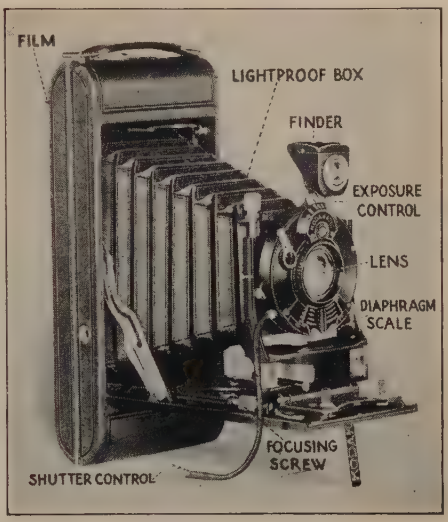
4. The *shutter*, which is like a small window-blind, and covers the lens opening. It is controlled by a lever or pushbutton, and is operated when everything else is ready for taking the picture. When the shutter is open, the light can stream in; hence the time during which it is open is important. In most cameras this time duration may be varied, in accordance with the amount of light available when taking the picture. If the light is strong, you set the pointer for an exposure of 1/100th of one second or 1 50th of one second. When you push the button, the shutter opens and stays open for only that length of time. If there is very little light, you may have to take a " time-exposure " and so you set the pointer at *T*. In such a case, you push the button once to open the shutter and then again to close it, counting the necessary seconds in between. If the light is too strong for a time-exposure and too weak for a snapshot, you set the pointer at *B*, in which case the shutter stays open for just the length of time that you keep your finger pushing the button.

5. The *diaphragm*, which controls the size of the lens opening. Since the image is sharper if the opening is smaller, it is always wise to use as small a lens opening as possible; but if the light is not sufficiently strong, it is necessary to open the diaphragm wide. Another sliding pointer on a scale which is usually attached to the lens frame controls the size of this opening. Setting the diaphragm is an important step in preparing to take a picture, yet most people forget to do it.

6. The *focusing scale*. In the cheaper box-cameras there is no such scale, for no matter how distant the object is from the camera, no special adjustment of the lens need be made. In the camera with bellows, the lens can be brought closer to, or moved farther away from, the film. The correct position for the lens is the one at which a sharp image is focused on the film; and this

position depends on how far away the object is from the camera. The focusing scale tells how far out to draw the bellows when the object is 6 feet away, 8 feet away, 10 feet away, etc., up to a distance of 100 feet.

7. The *finder*. This is usually mounted very close to the lens. As you look down into the finder, you see the object which you wish to photograph. If you are holding the camera at an angle or if you are not aiming the lens directly at the object, you will discover that fact in the finder. The finder consists of a miniature lens, a mirror at an angle of 45°, and another lens or piece of ground glass. The finder is usually hinged so that it may be turned to position when the camera is held sidewise.



57. Parts of a camera.

2. How to take a picture

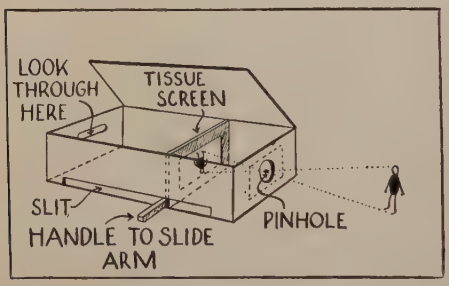
If you have become familiar with all the essential parts of the camera, you are ready to take good pictures. However, you must keep in mind the use of each part and the proper positions of object and camera, in order to get the best results. The following suggestions may be of help to you.

1. See to it that the object to be photographed is *in the light.*
2. Make sure that no direct beam of light shines into the camera lens. A good plan is to let the light come from behind you as you face the object.
3. Measure or estimate your distance from the object and set the focusing scale accordingly.
4. Decide on how strong the light is and move the diaphragm pointer so as to make the lens opening as small as you think necessary.

5. Set the pointer at *100*, *50*, *B* or *T*, depending on whether you think it possible to take a snapshot, a short-time exposure or a long-time exposure.
6. Make sure that the knob has been turned so that the next unexposed film is in place.
7. Find the picture in the finder.
8. Holding the camera very still (rest it on something steady, if necessary), push the button.
9. Move the knob at once to the next unexposed film.

3. How to take and make a picture with a simple camera

See figure 58. To make a sharp pinhole, bore a one-inch hole into the end of a cigar box, tack a piece of cardboard over the hole and push a pin through the cardboard. In the end opposite the pinhole, cut an opening, as shown. This will serve as the place into which to look. The screen on which the image is formed is a sheet of tissue paper glued to a framework of stiff cardboard. In order to slide the screen back and forth, cut a narrow slit in the side and attach a handle to the framework. The figure shows the box cover open, but the cover should be closed when the camera is in use. This is to exclude all light except that coming through the pinhole. For a similar reason, do not cut the slit too wide.



58. Pinhole camera.

An interesting modification of this device is to substitute a short-focus lens for the pinhole. This will give you images which are clearer and brighter, provided you focus properly on the screen. Also, you can take a real picture with such a camera by using photographic paper instead of the tissue. See page 70. In that case, cover the observation opening, insert the photographic paper (with the room darkened), and slide it into position for the best focus. Then direct the camera at the object and allow for proper exposure. The photographic paper is developed in the usual

manner. See page 71. The picture which results is, of course, a negative; that is, the white lines are all black and the black lines are all white.

4. In a camera an image is focused on a sensitized film

Do again the experiment described in figure 53 on page 56. If you have a camera, carefully unscrew the lens and use it in place of

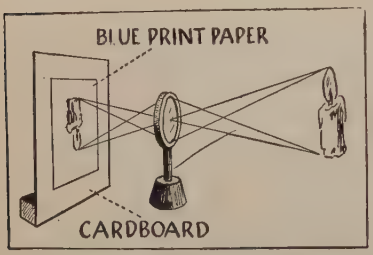
59. A positive and a negative.

the reading-glass lens. On the screen is a small inverted picture of the candle, but the picture is not permanent. Should you remove the candle, the lens or the screen, the picture disappears.

Now, Daguerre showed us how to prepare a surface so that it is sensitive to light. You will recall that in our account of the lucky accident which led to his discovery, he used silver plates fumed with iodine vapor. Of course, there are other substances which are sensitive to light and several of these substances were known even before Daguerre's time. The important thing was to find a substance so sensitive, that an image focused for a brief moment

on a screen covered with the substance would make a permanent impression on it. Try this experiment:

In a darkened room, set up a screen, lens and candle, as shown in figure 60. Find the position of the lens when the image is sharply focused. Let the candle be at least three feet from the screen. Blow out the candle and cover the screen with a sheet of blue-print paper. Light the candle and note the image on the paper. After a minute's exposure, blow out the candle again. Wash the blue-print paper in running water for several minutes. Does a picture of the candle appear on the paper? If it does not, repeat the experiment, exposing the paper for a longer time. The blue-print picture is fairly permanent, though not very good.



60. An image on blue-print paper.

5. The light affects the silver salt on the film

When Talbot discovered that paper surfaces covered with silver salts are very sensitive to light, he paved the way for modern photography. The celluloid films which we use to-day, as well as the glass photographic plates and the paper on which the pictures are finally printed, are all covered with silver salts.

Ask your teacher to give you a few crystals of silver nitrate. Dissolve the chemical in a small amount of water and paint with it a smooth sheet of writing paper. Do this in a fairly dark corner of the room. Now lay a coin on the paper and take it to the window, where the light is strong. After a few minutes remove the coin and examine the sheet. You will find that the paper has turned brownish, except where the coin has been. There, a clear white circle can be seen.

The chemist explains this experiment as follows: The light acts on the silver salt to break it up; that is, the light causes the silver in the salt to separate from the other substances with which it is combined. Since small silver particles are brown or black in appearance, the paper assumes that color wherever the light has

had a chance to shine. The light could not shine under the coin; hence, there remains a white circle where the coin had been.

In a real film, the surface is coated with gelatin in which silver bromide is suspended. When the lens focuses an image on this surface, silver particles begin to separate out wherever the light is focused.

6. After exposure the film is developed

The time of exposure is usually so short that very little silver deposit can form. It is necessary, therefore, to continue the deposit of black silver particles after exposure. You may recall that Daguerre used mercury vapor for this purpose. Many other things will serve. At present the chemical used for this purpose is very complicated, and unless you have studied chemistry you will not understand its action. However, you *can* learn its name. It is called *pyrogallic acid* (commonly called " pyro "), and is mixed with a certain amount of sodium carbonate and other chemicals.

When an exposed film is placed in a bath of " pyro," the latter continues the deposit of silver particles begun during exposure. This process is called *developing*. Photographers are careful not to under- or over-develop a film. They keep the exposed film in the developer just long enough to obtain a good deposit of black silver particles wherever the light has been focused by the camera lens. The developing *must* take place in a dark room.

At this point another very important thing must be done. Though the film now carries a black silver-deposit picture, there are parts of the film covered with unexposed silver salt which the developer has left unchanged. Should you take the film into the light, the latter would begin to form a silver deposit all over the film. The film would become black all over and the picture would disappear. Hence we must get rid of the unexposed silver salt before taking the developed film into the light.

In your experiment with the coin on a sheet of paper, the white circle in a brown background disappears after a time, because the light soon acts on the circle when the coin is removed. To retain a permanent " picture " of the coin, the paper must be " fixed." Try to do this by washing the paper in water immediately after removing the coin.

In the case of a film, " fixing " is accomplished by washing with a chemical called " hypo." The " hypo " dissolves completely all the unexposed silver salt, leaving a clear piece of celluloid on which the picture is indicated in lines of black silver particles. After the film has been " fixed," it may be taken into the light.

The film is now a *negative*. On the negative every white portion of the object is indicated by a heavy deposit of black silver particles. Those parts of the object which are black did not send much light into the camera, and so on the negative they are represented by little or no silver deposit at all.

7. Photographs are printed from negatives

Since you probably have many negatives of pictures which you have taken and have had developed by a photographer, try to print a picture from one of them yourself. You will need the following materials:

a. A package of printing paper. When you buy this at a photography store, ask for the slow-acting kind.

b. An MQ tube. This contains the developing chemicals and may be bought for two or three cents at the same store.

c. Some " hypo " for " fixing " the print. This also may be purchased at the same store.

d. Three large soup plates or trays to hold solutions.

e. Two small squares of window glass.

Proceed as follows:

In a fairly dark part of the room, dissolve the entire contents of the MQ tube in a plateful of water. Dissolve a teaspoonful of " hypo " in a second plate of water. Fill the third plate with water and set it between the other two. Lay the negative on one of the squares of glass, with the dull side of the negative facing up. With your hands in a drawer which is closed as far as it will go, take a sheet of print paper from the package. Quickly, remove the paper and lay it on the negative. Be sure that the smooth, chemical-covered side of the paper is next to the negative. Now cover the paper with the second glass frame, so that the negative and paper are held in close contact. You are ready to expose the negative to the light.

As a source of light you may use window light or an electric lamp. Of course, the strength of the light determines the length of the time exposure. You will have to learn the right length of time by experience.

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61. How a positive is printed from a negative.

Immediately after exposure, immerse the print paper in the developing solution. Bathe the paper gently with your fingers until the picture appears. When it does, lose no time. Remove it quickly, dip it into the water for a moment and then lay it, face down, in the "hypo" solution. After about five minutes it will be "fixed," and you can then remove and dry the photograph.

The photograph obtained is a *positive* made from the *negative*. During exposure the light falls on the black silver lines of the negative, but they do not go through to the paper. So, after developing, every black line of the negative leaves a white line on the paper which was under it. The light does go through the clear parts of the negative. Under these parts the paper, when developed, shows black lines. Different shades of blackness in the negative show up as different shades of whiteness in the photograph.

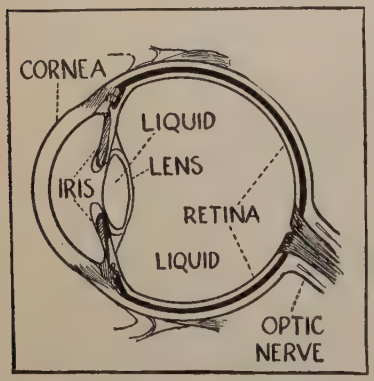
The process of printing a photograph from a negative is almost exactly the process used by the photographer when he develops the negative itself. He uses the same MQ developer and the same hypo fixing solution. However, he does the work in a room which is perfectly dark, except for a dim red light. Red light affects the film but very little.

8. The eye is like a camera

In the table below, the eye and the camera are compared. For each essential part of a camera there is a corresponding part of the eye. Also, the eye does practically everything the camera does.

COMPARING THE EYE WITH THE CAMERA

The Camera	*The Eye*
Camera Lens	Eye lens
Film	Retina[1]
Lightproof Box	Eye-Socket
Diaphragm to Control Lens Opening	Iris
Snapshot	Blink
Time Exposure	Stare
Focus by Changing Lens Distance	Focus by Changing Lens Curvature
Pictures Are Permanent When Developed	Pictures Last about 1/16th of a Second
Pictures Are Black and White	Pictures Are in Natural Colors
Finder Is Necessary	No Finder Is Necessary



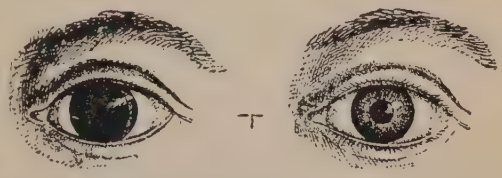
62. The eye is like a camera.

Figure 62 is a diagram of the human eye. After passing through the cornea and the pupil, the light is focused by the lens as an inverted image on the retina. The latter is sensitive to light; it is stimulated by the image. The stimulus is carried by the optic nerve to the brain. There, by a process which we do not understand very clearly, the stimulus is changed to the sensation which we call *seeing* or *vision*.

When light falls on a film, the film is changed and can be developed into a permanent picture. If it falls on the film for too long a time, the film is spoiled. The retina, too, is changed in some way when light falls on it, but the pictures are not permanent. After about 1/16th of a second the stimulus disappears and we do not see the object any longer, unless we continue to receive light from the object. After each stimulus, the sensation stops and the retina is ready for a new picture. The retina

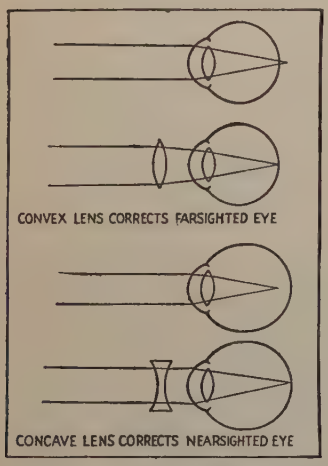
[1] The retina is a network of nerve fibres in the eye, on which images are formed. We see when the retina is stimulated by light.

behaves like a film in which the sensitive chemical is continually renewed. Of course, if the light is too strong, the retina may get tired. One might even injure the retina seriously. In that case blindness would result. Many people have become blind by looking directly at the sun.



63. How the iris acts to exclude too much sight.

The above suggests the purpose of the iris, which is like the diaphragm in a camera, and can open wide, or narrow down to almost a pin-point. The iris, by controlling the amount of light which enters the eye, protects the retina from too strong a stimulus. In a dark room, the iris opens wide to let in as much light as possible. Outdoors, the iris opening becomes small. The interesting fact about the iris is that it opens and shuts without our knowledge. It protects the retina (to a certain extent) without requiring much help from us.



64. How eye-glass lenses can correct farsightedness and nearsightedness.

Nevertheless, we should be as helpful as possible by forming good eye habits. Do not let direct beams of light enter your eyes. Glazed paper and polished tabletops reflect too much light and will tire the retina, if your eye is in a position to receive the reflected light for too long a time.

If the cornea is distorted in some way, or if the eye muscles which control the lens curvature have ceased to function properly, vision becomes defective. Images are no longer focused *on* the retina, but in front of it or in back of it. The nearsighted eye has a cornea or lens which is so convex that images come to a focus in front of the retina. In order to correct this difficulty an eye-glass

which is *concave* is placed in front of the eye. The concave eye-glass reduces the convexity of the cornea and eye lens, so that images are focused sharply on the retina. The farsighted eye has a cornea or lens which is not convex enough; so that images would focus somewhere in back of the retina. In order to correct this difficulty an eye-glass which is *convex* is placed in front of the eye. The convex eye-glass increases the convexity of the cornea and eye lens, so that images are focused sharply on the retina (figure 64).

Frequently, the cornea may be so distorted that an eye-glass is specially ground to make up for these distortions. A person with *astigmatism* is probably the owner of eyes which are distorted in this way. If eye-glasses are correctly fitted and properly used, such eye defects will not be troublesome.

HOW MUCH DO I REMEMBER?

Write your answers on a sheet of paper so as not to mar the book.

A

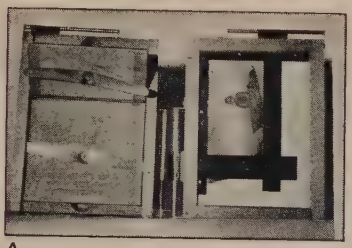
The list below gives important steps in the history of photography. Arrange the steps in the order in which they occurred, and give the name of the man connected with each.

A. Discovered a gelatin film to be used as a plate.
B. Developed a permanent picture on a metal plate covered with asphalt.
C. Discovered "hypo" for fixing the picture.
D. Invented the camera obscura.
E. Discovered that mercury vapor can be used for developing pictures on certain metal plates.
F. Discovered a substitute for mercury vapor in developing pictures.
G. Discovered that pictures could be made on paper treated with silver salts.

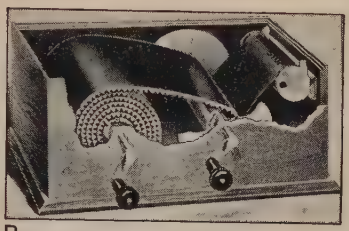
B

Give the names of the parts of the eye and of the camera which perform each of the functions listed below. Write your answers in two columns, one for the eye and one for the camera. If there is no part which performs any given function, say so.

1. Focuses the image.
2. Serves as a screen on which the image falls.
3. Excludes all light except that which comes through the lens.
4. Controls the size of the lens opening.
5. Opens or shuts the lens opening completely.
6. Moves the lens closer to or farther away from the screen.
7. Forms a separate image of the object on a piece of ground glass.



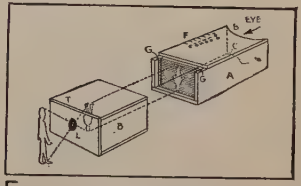
A



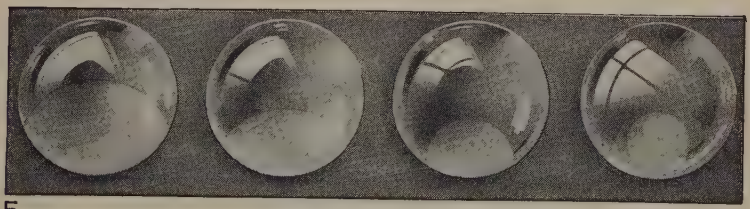
B

C

D



E



F

A. Front and back views of a printing frame. How is the printing frame used?
B. What is this? What is its connection with photography?
C. What is she doing? Find out about this process and report to the class.
D. How to hold the film when you are developing a negative. What is in the tray?
E. Make this camera in the school shop.
F. These are bi-focal lenses. Why are they used? Who uses them?

C

Tell whether each of the following is true for "the camera," "the eye," "both," or "neither."

1. It has a concave lens.
2. It sometimes requires a time exposure in order to produce an image.
3. The lens must be adjusted to the distance of the object from the camera.
4. It is important that no direct beam of strong light shine into the camera.
5. Light affects silver salts.
6. The image must be developed.
7. The image must be fixed.
8. The image must be printed.
9. The image is focused by changing the lens curvature.
10. The image produced on the screen is inverted.
11. The part which acts as a screen retains the image for only about 1/16th of a second.
12. It does not need a finder.
13. The image formed is in natural colors.
14. It is possible to control the amount of light entering the lens.
15. The image is focused on a sensitized gelatin film.
16. It sometimes has a defect called astigmatism.

D

"The steps in making a photograph are (1) exposure, (2) developing, (3) fixing, and (4) printing."

1. Are the steps given in the correct order?
2. Before which step must focusing take place?
3. During which step is the lens used?
4. Which step produces the negative?
5. Which step produces the positive?
6. During which steps do we use "hypo"?
7. During which steps do we use pyrogallic acid?
8. During which steps does light affect silver salts?
9. During which steps must all light, except red, be excluded?
10. During which steps are the unexposed silver salts washed off?
11. Is it true that during the printing, the printing paper must be covered by the negative and exposed to the light?
12. Is it true that the printing paper must be "developed" but not "fixed"?
13. Is printing too complicated a process for one to try himself?
14. Is the actual photograph a negative or a positive?

THINGS TO THINK ABOUT AND READ ABOUT

1. Long distance photography is of great importance. How to get a picture of a distant object without approaching it, how to photograph the most distant stars, how to send a news picture across an electric wire

with the speed of electricity,—these are problems which were not solved at once but which took years of research.

Distant objects are photographed through the telescope. The telescopic camera has helped to discover new stars, and to compare their brilliancy. It has spared the astronomer arduous hours of incessant watching. In fact, next to the telescope itself, it has done most to help map the skies. Read

Book O, page 2552; Book P, pages 243, 1783, 2653, 2588, 2963, 3832, 3834, 4497.

2. Picture transmission across wires depends on peculiar properties of certain substances. The substances selenium and potassium conduct electricity; but when light falls on them, their conductivity is even better. The stronger the light, the better is the conductivity. In this way, variations in light from a picture shining on a selenium or potassium tube cause variations in the electric current received at the other end. There the current is changed back again into the picture. Read
   Book O, page 3174; Book P, pages 5179–5182.
3. Just as the telescopic camera is used to photograph distant objects, so the microscopic camera is used to photograph minute objects. With a microscopic camera we can photograph the tiny forms and structures of life; we study the minute imperfections of steel; we perform countless jobs of science and industry. If a scientist makes a discovery through the microscope, he can only tell us about it. If the microscopic camera has photographed it, we can all see it. Read
   Book O, page 474; Book P, pages 237–254, 2906. Also review the references given for the microscope in Chapter III.
4. Undersea pictures are taken from a water-tight chamber which is lowered into the water. Powerful lights attract the fish which are photographed through a thick glass window. Read
   Book O, page 2342.
5. Most moving pictures are taken in the strong artificial light of the studio. Some brilliant samples of night photography can be found in
   Book P, pages 3619, 3767.
6. Pictures taken from airplanes and pieced together systematically are providing us with cheaper and better maps than any surveyor can hope to produce. Aerial pictures taken by the Byrd expedition mapped 150,000 square miles of Antarctic territory. A good picture taken from the air may be seen in
   Book P, page 3837.
7. The story of photo-engraving.
   Book K, pages 380–382.
8. Making films and plates.
   Book O, pages 2780–2782; Book P, page 2654.
9. The sun as an artist. The story of photography.
   Book P, pages 2649–2664; Book K, pages 162–168.

10. More about Joseph Niepce.
    Book O, page 2784; Book P, pages 4224–4225.
11. More about Louis Daguerre.
    Book O, page 2784; Book P, pages 1420–1421, 2650–2651; Book K, page 164.
12. In Volume I of a book called "A Popular History of American Invention," published by Charles Scribner and Sons, you will find a very good story of photography. "Putting Sunlight to Work" is the title of a chapter to be found on pages 379–418.
13. The eye and vision.
    Book P, pages 2633–2639.

THINGS TO DO AND MAKE

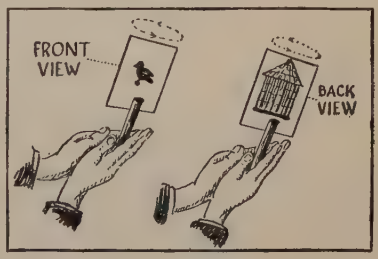
1. Experiments with photo-chemistry.
   Book D, pages 292–297.
2. Making a dark-box and dark-room.
   Book I, pages 6–7.
3. Experiments with the camera obscura and pinhole camera.
   Book D, pages 132–135; Book E, pages 284–292; Book I, pages 9–12, 121–122.
4. Making a camera.
   Book B, page 214.
5. Fun with photography.
   Book E, pages 281–284.
6. How to make a direct-view finder for cameras.
   Book H, page 54.
7. Lighting a room for making photographs.
   Book H, page 123.
8. How to make a small photographic work-table.
   Book H, pages 215–216.
9. How to make a developing sink for an amateur photographer.
   Book G, pages 33–38.
10. Making a developing tray.
    Book H, pages 121, 224, 228.
11. An easy way to develop roll film.
    Book H, page 425.
12. How to enlarge photographs.
    Book H, pages 217–222; 232.
13. Tricks in printing pictures for the amateur.
    Book H, pages 33, 92, 97, 168, 170, 241, 371.
14. Camera surveying and plotting a camera survey.
    Book H, pages 7–11, 12–18.
15. Stereoscopic pictures with an ordinary camera.
    Book H, page 346.

CHAPTER V

PROJECTION LANTERN AND MOTION PICTURES

A young man once tried a foolish experiment. He gazed at the sun for 20 seconds in order to see what would happen to his eyes,—and he became blind. This was such a reckless and unnecessary performance that we should not take the time to tell about it, were it not for the interesting consequences.

Joseph Plateau was one of those boys who liked to know about everything. He had a desire to explore unknown fields. Very early in life he became interested in the making of pictures. He read every book that he could find on the subject, and he performed as many of the experiments described in these books as he could get materials for. He was especially interested in a picture toy devised by a Doctor Paris, in which a bird appeared to be inside of a cage, although the bird and the empty cage were drawn on opposite sides of a card. The card, mounted on a stick, was twirled rapidly in order to show the effect. The explanation, which interested him greatly, was that the eye retains the image of the cage until the bird image forms on the retina. "Vision persists," Herschel had said,[1] "and some day we shall utilize this idea to represent scenes in action by photography."



66. The bird seems to be in the cage.

Plateau studied the persistence of vision in the hope of making Herschel's dream come true. No doubt his rash attempt to gaze long at the sun was one of his many experiments to learn more about vision. To become blind at the age of 28 is a terrible thing. It would have meant defeat for most men; yet Plateau kept on regardless of his blindness. For a while he regained his eyesight

[1] This is the same man who discovered the action of "hypo." See page 65 and Chapter IV.

and doubled his efforts. He became a professor of Physics at a university, but at the age of 42 he was totally blind again. Even then he continued to experiment, enlisting the aid of his family, who carried out his directions and reported what happened. Strangely enough, some of his best work was done in this way.

His great achievement was a machine which many regard as the first motion picture projector. It was crude, but it set men to thinking. Sixteen pictures, placed around the edge of a rotating disk, were shown in a flickering light. Each picture was viewed for but 1/16th of a second. The movement from picture to picture was not seen because the light went out during the motion. Since each image persisted until the next one came, an illusion of continuous motion was produced.

Now, most of the world's great inventions are the results of the work of many men. It would hardly be fair, therefore, to credit the " movies " entirely to Joseph Plateau. Those who followed him made important contributions and among these several should be mentioned. First, there was Seller's method of putting pictures on an endless flexible band, which was an improvement on Plateau's disk. Then came Muybridge's work in photographing moving objects with a battery of cameras. As the object moved, it cut strings in its path and the strings clicked the cameras to which they were attached. Thus the object was photographed at every stage of its motion. By throwing on the screen the still pictures thus obtained, at the rate of 12 or more a second, he created the effect of a running horse or of a pitcher throwing a baseball. In 1885, Goodwin invented the celluloid film, which was quickly adapted by Morey and others to a series of pictures on a long flexible strip of film. In 1886, Le Prince patented a sprocket device requiring perforated film, and two years later Edison perfected all devices known up to that time in his " kinetoscope."

The kinetoscope, however, was but a peep-show; for only one observer at a time could look into the machine. Its source of illumination was the flickering light of an electric spark. It was not until 1894 that the first modern type of projector was built by C. Francis Jenkins. For the first time, life-size motion pictures from a narrow strip of film were projected on a screen so that all could see.

Jenkins was awarded a patent for a machine which differed in several ways from any previous ones. His source of light was continuous and steady; the screen was fixed, the projector was stationary. The only thing that moved was the film, and it moved in jerks. An electric motor turned a pegged wheel, each peg fitting into holes on the edge of the film and dragging down the film so as to unwind it from a spool. As the film passed before the lens, it stopped long enough to let a beam of light pass through it. The picture appeared for an instant on the screen, only to make way a sixteenth of a second later, for the next picture. During the motion from one picture to the next, a shutter passed in front of the beam so as to hide the movement from the audience; but the latter saw a continually lighted screen, for the *vision persisted.* Merging one still picture into another in this way created the effect which Herschel had dreamed about, and which hundreds of experimenters had strived for with only partial success.

When Jenkins showed his first "movie" to the public, people refused to pay admission until they had seen the miracle first. What rapid progress has been made in 25 years! Jenkins lives to see his machine used in thousands of theatres where people come by the million, only too glad to pay their money in advance.

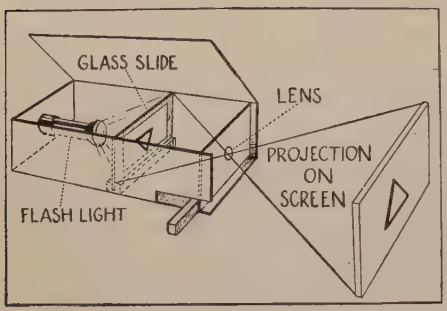
1. The projector lens forms an inverted, enlarged image on the screen

In Chapter III, page 56, we studied the formation of images by a convex lens. We learned that the size of an image depends upon the distance of an object from the lens. If the object is placed at a distance from once to twice the focal length of the lens, the image when focused on a screen is enlarged and inverted. This method is employed in all projectors, whether they be for still lantern slides or for motion picture film.

Let us study the essential parts of a projector by building a simple model.

In figure 67, you see a cigar box with cover open, so that you may see the details of construction. When in use this cover is closed. The front end has been removed and in its center a short-focus convex lens has been inserted. This lens carrier is slightly

reduced in size and attached to a supporting stick so that it may be slid back and forth as shown. The box is selected so that its size is large enough to carry the usual glass slide. Note how this slide is supported. A flashlight illuminates the slide, and the lens focuses an enlarged, inverted image on the screen. In a darkened room, using a fairly strong flashlight, a clearly visible image 2 feet square may be obtained.



67. A simple cigar-box projector.

If the focal distance of the lens used in this device is 6 inches, then the slide must be placed at a distance from the lens which is anywhere between 6 inches and 12 inches. It would be interesting to make two lens carriers, one with a 6-inch focus lens and another with a 4-inch focus lens. Notice the effect which each lens has on the size of the image on the screen. At any particular distance from the screen, the shorter focus lens gives the larger image. Of course, making the image larger spreads out the light over a larger area and causes the image to be less bright.

By operating this homemade lantern, you can understand why slides and motion picture film are inserted upside down. Since all the rays cross at the lens, there is an inversion, not only of top and bottom, but also of the left and right sides of the slide. This you can tell very readily by making a slide out of a clear piece of glass on which you have written a word with black ink. In order to make the word read properly on the screen, you must insert the slide upside down and right-side left. Motion picture film must also be inserted in the projector with this double inversion.

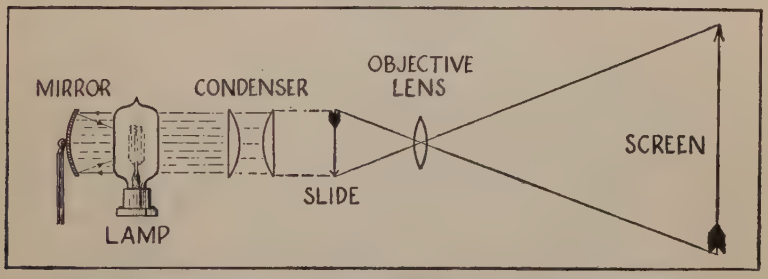
2. The more light on the object or the nearer the light to the screen the brighter is the image

Although our homemade model embodies the essential parts of a projector, two or three other parts are usually added in order to get better results. In large theatres or school auditoriums it is

necessary to project very large and very bright images on the screen. For this, more light is needed. Instead of a flashlight, powerful electric lamps are therefore employed. Frequently, the electric arc is used, which gives the hottest and brightest light obtainable by man.

Since a light shines in all directions and since our purpose in a projector is to throw light on the screen only, a curved mirror is placed in back of the lamp or arc-light to reflect forward as many of the rays as possible.

However, the slide is at some distance from the lamp and the lamp's rays spread out a good deal before falling on the slide. In



68. How the important parts of a projector are arranged.

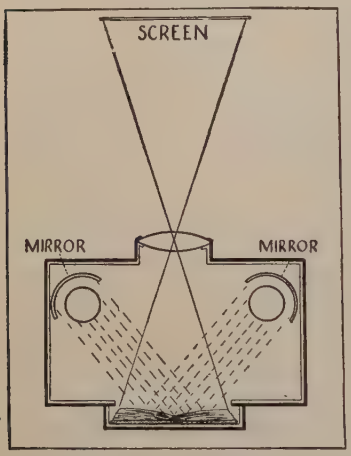
order to concentrate the beam and spread it uniformly over the slide, two lenses, known as the *condensers*, are usually employed. Figure 68 shows the usual arrangement of a modern slide projector. In a motion picture projector the slide is replaced with a moving ribbon of film.

Another type of projector which is much in use to-day is the so-called "opaque projector." In this case a lens forms an enlarged image on the screen of a postcard picture, a book or some other object which is opaque to light (see page 23). Figure 69 is a diagram showing the arrangement of parts. Note that there are no condensers in this type of projector.

One of the problems in all projectors and especially in opaque projectors is the tendency for the heat to crack the slide or burn the picture. In the case of motion picture film, the heat of the lamp or arc-light may set fire to the highly inflammable celluloid. Fortunately, the film is moving rapidly; but sometimes the film

breaks, jams the machine, and is exposed to the intense heat. Fire and even an explosion may result. That is why all motion picture apparatus is required by law to be in a fireproof booth and only a licensed operator may show motion pictures in an auditorium or theatre.

In slide projectors some of the heat is removed by providing air-holes for ventilating the lamp housing. In the opaque projector special motor-driven fans are sometimes installed. Even water-coolers are sometimes used to remove some of the heat. In the case of motion picture films, the only attempt to eliminate the danger of fire has been to provide a metal shutter which automatically hides the light from the film the moment the machine slows down. Also, a film which burns less rapidly (non-inflammable film) has been devised and its use is required by law.



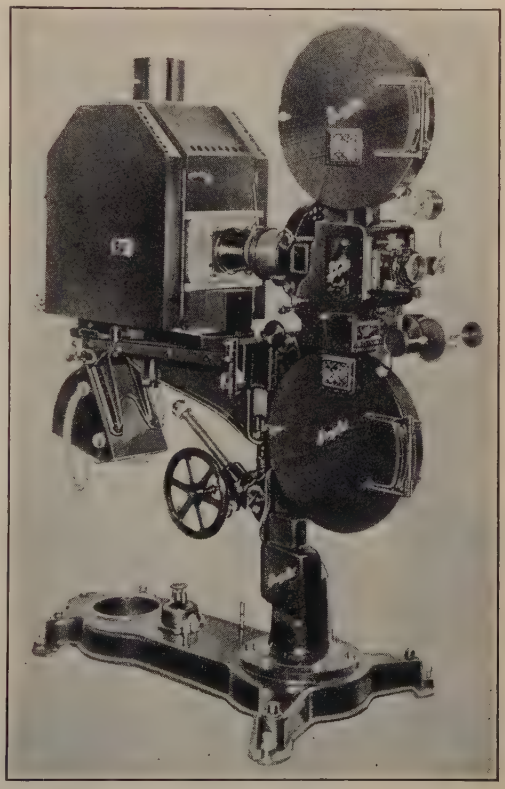
69. How the important parts of an "opaque" projector are arranged.

The problem of removing heat and preventing fires is especially difficult since theatres are being built larger and larger. In Roxy's Theatre, the distance between the screen and the source of light is more than 200 feet. Hence, a very intense source of light is necessary, in order to obtain a bright image on the screen. The brightness of the image depends more upon this distance than upon anything else. By bringing the light twice as near to the screen, four times as much light is available. By bringing the light three times as near to the screen, nine times as much light is available.

3. The eye retains the image of an object or a picture

Two thousand years ago it was known that vision does not stop when an object is removed from sight. All our lives, we blink our eyes, and in doing so we shut off our view, yet, we are not con-

scious of interrupting our sight. An image is retained on the retina for a short time after the object has changed its position or has disappeared. If we swing a lighted stick, the eye sees a continuous flaming circle, for the image of the flame in all of its positions is retained on the retina. As we have already learned, this fact is referred to as the *persistence of vision* and is the idea on which the moving picture is based.



70. The modern motion picture projector.

Careful measurement shows that vision persists for about 1/16th of a second. Try the following experiment:

Prepare a series of cards on which you show a ball hit by a bat. Each card shows the ball a bit farther from the bat than on the card preceding it. Now ruffle the cards with your thumb and observe the pictures intently. It will seem to you as if the ball is moving away from the bat. If in this experiment the cards flash by at the rate of 16 a second, the illusion of motion is perfect. If only ten or less are seen in one second, the motion will be jerky. If more than 16 flash by in a second the movement of the ball seems more rapid. Figure 72 C, page 93, shows how the cards may be held.

4. The motion picture operates so as to take advantage of the persistence of vision

If, in a slide projector, you could change the slide 16 times a second, you could produce the illusion of motion on the screen. Since this is practically impossible, a series of pictures are photographed on a long ribbon of celluloid film. Each picture is about 1 1/4 inches wide and 3/4 of an inch long. The action progresses from picture to picture. When the pictures are photographed, 16 pictures are taken each second; and when they are projected, the same rate is employed through the machine.

In its movement through the machine, each frame comes to a full stop in the path of the beam of light. After 1/16th of a second has passed, the sprocket wheel jerks the film down a distance of 3/4 of an inch, so that the next frame is shown on the screen. During the shift from picture to picture, a pinwheel shutter hides the light from the screen, but the persistence of vision keeps an image on the screen all the time. The purpose of the shutter is to avoid a very annoying flicker on the screen.

The usual " feature film " is about 5 reels in length. A reel is about 1,000 feet long. Every foot takes one second to pass by the beam of light. Hence, a five-reel feature takes 5,000 seconds or about one and one-half hours to show. Since every foot of film contains 16 pictures, 5,000 feet of film contain 80,000 pictures. In other words, during a one and one-half hour " movie " show, 80,000 pictures are flashed on the screen.

If the motion of the film is speeded up, the moving image will also speed up. Sometimes, it is desired to make a train move faster on the screen than in reality. In such a case, the motion picture camera photographs the train at a rate less than 16 pictures per second. When run off at the normal rate the motion on the screen is speeded up. By this method a seed which may take a month to grow into a mature plant, does so in a few seconds on the screen.

In " slow-motion " pictures the opposite procedure is employed. Many more than 16 pictures a second are taken by the camera. Recently we have learned how to take 20,000 pictures in a second. When these pictures are projected at the rate of 16 per second, the fastest moving object just crawls along. Bullets shot from

guns move leisurely across the screen and their effects upon objects which they penetrate may be studied by men of science.

5. Some recent developments in motion pictures

The first of these developments may be called the "Home Movie." Projectors and cameras have been built which employ a film that is only about half an inch wide.[1] This reduces the cost

71. Movies in the home.

of the film, the size and cost of the camera and projector; and makes the taking and showing of pictures a much more simple process. Since the distance between light and screen in the home can be much shorter than in a theatre, the lamp need not be very powerful or very hot. Also, the narrow film is usually made of non-inflammable (slow-burning) material, so that the danger of fire is practically eliminated.

Another development in the motion picture theatre is the "grandeur" effect. In the midst of a show, the screen suddenly enlarges so as to fill the whole front wall. The audience gets the illusion of actually being in the world in which the actors are playing. This effect may be produced by shifting the film to a projector that is equipped with a shorter focus lens or, as is more often the case, by projecting film that is nearly $2\frac{1}{2}$ inches wide.

[1] The film is 16 millimeters wide.

Still another improvement in the theatre is the Technicolor motion picture. By an elaborate chemical process, film is made on which the natural colors of scenes are photographed. When projected, the screen images appear in colors which are nearly like those of real life. The effects are often beautiful and bring the motion picture drama one step nearer to stage presentations by living actors.

6. The motion picture may be combined with sound effects

When sound effects are added to the " grandeur " film and the Technicolor process, the illusion on the screen is almost complete. It was one of Edison's dreams to combine his phonograph with his kinetoscope. He was, perhaps, the first to think of the idea of a " talking " motion picture and to experiment with the idea. In 1913 he exhibited the first " talkie," but its defects were so many that he gave it up. In the meantime, others carried on the experiments and in 1926 Lee De Forest invented a new method for making " talkies." At about the same time engineers of the Western Electric Company devised still another method. In fact, the " talkies " we hear and see to-day are of three types. Only one kind, the Vitaphone, records the sounds on wax-like records, in the manner of the phonograph. This is done at the same time that the film is being taken and when the latter is thrown on the screen the record is played in the usual way at a speed which matches the sound exactly with the action. Matching sights with sounds is called synchronizing.

In De Forest's method the vibrations of the sounds to be recorded are allowed to produce tiny and variable electric currents. These change the brilliancy of a special kind of lamp. The flickering lamp shines on the moving film in the camera which is taking the picture, and there makes a photographic record of the sounds. When thrown on the screen, the sights and sounds synchronize exactly, since they have both been recorded side by side on the same film.

In the third type of " talkie " the sound vibrations to be recorded are again allowed to produce tiny and variable currents. But these currents control the flickering of a small shutter. The latter interferes with the light coming from a steady lamp and

which, as before, is shining on the film in the camera. Again a photographic record of each sound is made on the film right next to the action which produced it.

In each of the three kinds of " talkie " a radio amplifier magnifies the sound so as to fill the theatre.

HOW MUCH DO I REMEMBER?

A

Fill in each empty space with the name of the proper inventor and then arrange the sentences in the order in which they occurred. Write your answers on a sheet of paper so as not to mar the book.

1. ..... invented the kinetoscope.
2. The fact that vision persists was discovered by .....
3. ..... invented a successful method for synchronizing sound with the film.
4. ..... first placed the moving pictures on an endless flexible band.
5. ..... invented the celluloid film.
6. ..... made the first machine in which pictures placed around the edge of a rotating disc were shown in a flickering light.
7. ..... patented a sprocket device for moving the film.
8. ..... invented the first modern type of "movie" projector.
9. ..... used a battery of cameras to photograph moving objects.

B

Which of the following statements are true only for motion picture projectors? Which are true only for still picture projectors? Which are true for any kind of projection machine? Which are false? Write your answers on a sheet of paper so as not to mar the book.

1. The projector lens forms an inverted, enlarged image on the screen.
2. The picture must be placed from once to twice the focal distance from the lens.
3. Pictures on glass slides are projected.
4. A concave lens is used as a projecting lens.
5. The picture must be inserted upside down and right-side left.
6. A curved mirror is placed in back of the source of light.
7. Condensing lenses are usually employed to concentrate the light.
8. It is possible to project images of opaque pictures.
9. There is the problem of removing the heat caused by the powerful light.
10. The persistence of vision is of great importance in the projection of pictures.
11. Pictures are projected at the rate of 16 times a second.
12. Pictures move past the projecting lenses without stopping.
13. Pictures are always printed on a long ribbon of celluloid film.
14. Pictures are always $1\frac{1}{4}$ inches wide and $\frac{1}{4}$ of an inch long.

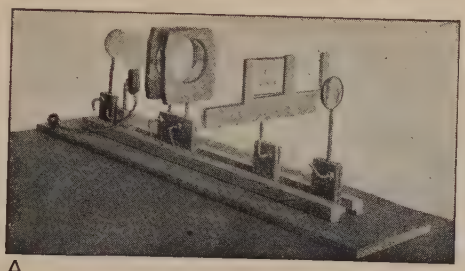
15. Each picture is jerked down by the sprocket wheel, while a pinwheel shutter hides the light from the screen.
16. Objects are always shown moving at their normal speed.
17. Pictures cannot be shown in the home.
18. Pictures may be projected in natural color.

THINGS TO THINK ABOUT AND READ ABOUT

1. The story of the motion picture projector. You will also find this fascinating story in the book, "A Popular History of American Invention," Volume 1, pages 419–444. Read also,
   Book O, pages 2341–2356, 2777–2784; Book P, pages 2776–2792; Book K, pages 575–579.
2. The stereopticon. This name sounds complicated, but it is another name for the projection lantern. You will find more about it in
   Book O, pages 3353–3354.
3. Speed photography.
   Book P, page 4290.
4. Talking movies. After reading these references, do you think that they were written recently? Why?
   Book P, page 2778; Book K, page 536.
5. Another book that will interest you is "With the Movie Makers" by John Amid. It is published by Lothrop, Lee & Shepard Co., Boston.

THINGS TO DO AND MAKE

1. The "Bird in the Cage," phantom forms, and other optical illusions that depend on the persistence of vision.
   Book C, pages 287–297; Book D, pages 126–129; Book E, pages 296–304; Book I, pages 123–126.
2. Other illusions of motion, easily produced.
   Book E, pages 293–296; Book G, pages 312–316.
3. How to make a simple magic lantern.
   Book D, pages 127, 138–139.
4. Making a postcard projector.
   Book I, pages 119–121.
5. Making a reflectoscope to project postcard and other opaque pictures.
   Book D, pages 139–142; Book E, pages 304–309.
6. Making a simple motion picture machine.
   Book H, page 132.
7. Homemade motion picture camera and projector.
   Book H, pages 198–200, 202–205.



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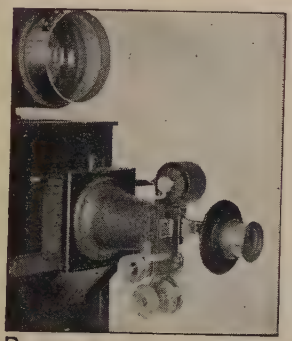

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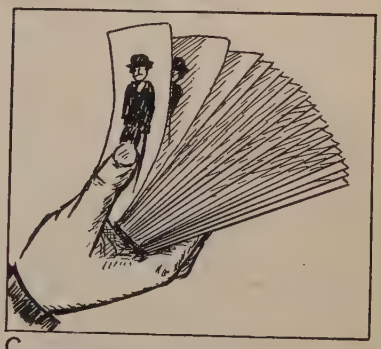

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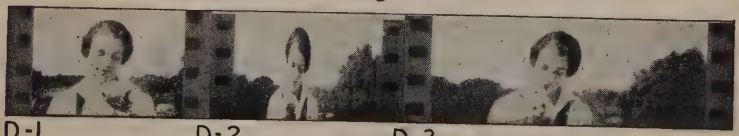
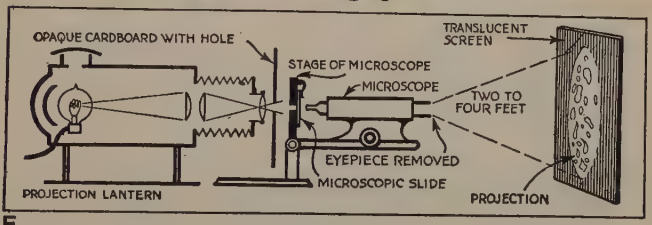


D-1 D-2 D-3



E

A. Make this model of a slide projector in the school shop.
B. This is a filmslide attachment. Find out its purpose in a projector.
C. Shuffling these cards makes the picture seem to move. Make a set of cards showing Babe Ruth hit a baseball.
D. One method of filming pictures for the "wide" screen. Can you explain how D-2 may be projected so as to appear as D-3?
E. Try this method of projecting microscopic slides.

CHAPTER VI

COLOR

A modern factory is a busy place. Everything is done according to schedule and each department must work at top speed so as to fit in with the needs of every other department. When one group of workmen becomes less efficient the output of the entire organization suffers.

Now, this was the case in a certain New England factory, not long ago. In one section of the plant the men seemed dissatisfied. They complained, they tired easily, they quarrelled and they made mistakes. The manager investigated, transferred men to different departments, discharged certain others, but with little result.

Finally, the thought occurred to him that perhaps the fault lay not with the men but with the workroom. He himself could see nothing wrong and so he called in experts. These experts were scientists and among them was a lighting engineer. After careful inspection this engineer arrived at a conclusion.

" The trouble with this room," he said, " is that it is illuminated with the wrong color light. The amount of light is ample, but all artificial light is yellowish in tint. Now, you will notice that the chief task of a workman in this section of the factory is to fit a small yellow part into a larger device, also somewhat yellowish in color. In this light the two objects look so much alike that it is a strain on the eyes to see one against the other."

" Well, what would you suggest? " asked the manager.

" Put in *bright blue* lamps," was the reply.

This was done at once. In the blue light, the device and the parts, which were of different shades of yellow, assumed new and sharply different colors. One looked gray and the other looked brown. They were easy to see and easy to fit together. Trouble with the workmen soon ceased and the efficiency of the factory was raised.

Many more examples can be given of the effect of color on the quality of work accomplished. We are only beginning to realize

its importance and to study the problem scientifically. There are several experimenters who claim that a red color excites the emotions; that an orange color puts one in high spirits; that yellow stimulates the body; that green is a normal, neutral color; that blue results in physical depression; that violet makes one sad and that purple subdues the spirits. Much more investigation is needed before we can accept all this, but there is some truth in the findings. It is certain that color is more important in life and in work than was thought to be the case a few years ago.

The world would be a dreary place if everything in it were either white or black. Yet there are men and women who are color blind. A deep red rose is to such people only a cluster of blackness; the leaves of a tree are all a dull white. They see clear blue sky as a dome of granite gray, and leaping flames give them the impression of a fog.

Then there are certain animals whose sight, though not confined to black and white, is deficient in some of the colors. Bees and fish, according to several investigators, see only blue and yellow. Everything else is some shade of black or white. Cats are believed to be entirely color blind.

The use of color is increasing daily. Newspapers, magazines and advertisers are introducing color in their appeal to the public. Uninteresting books are sometimes sold because of their beautifully colored bindings. Stores, window displays, hotel lobbies and even the exteriors of buildings are dressed up in colors so as to attract favorable attention. In most instances they succeed because the effects are pleasing. Chemists are to-day producing hundreds of new shades, hues and tints because there is a demand for colorful surroundings of every sort.

In the theatre, moving pictures in natural colors have become extremely popular, and on the stage the scenic artists have learned to make use of colored light to suggest ideas and emotions which help along the efforts of the actors. By changing the color of the light, the same scene may take on a different appearance. An actor dressed in red when the stage is flooded with white light suddenly appears in black as the electrician switches on the blue lamps.

Let us then conclude our study of light by considering several important ideas about color.

1. Light from the sun consists of, and may be separated into, lights of many different colors

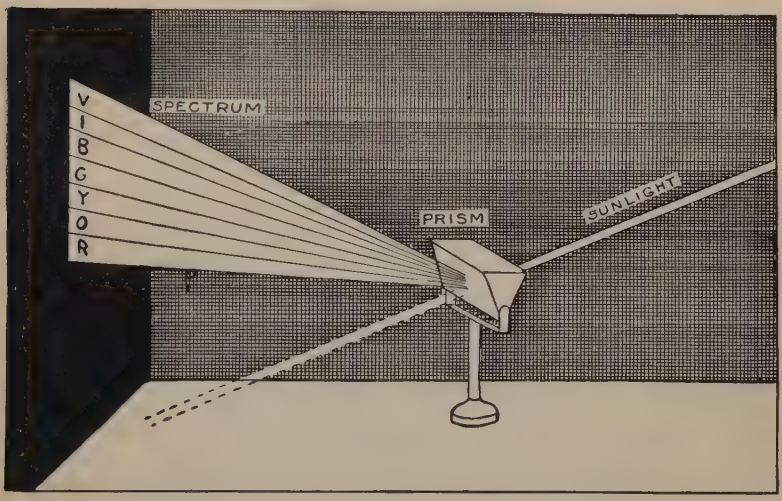
One of the most beautiful sights in nature is the rainbow. Shortly after a rain, in the afternoon of a summer day, the sun sometimes produces a semi-circular bow of colors which stretches across the eastern sky. When conditions are right, the bow seems to touch the ground at the horizon. The colors, beginning from the inside of the arc, are violet, indigo, blue, green, yellow, orange and red. Frequently, a second bow, larger and fainter than the first, may be seen a short distance higher up in the sky. The colors in this bow are reversed, with red on the inside and violet on the outside.

When sunshine falls on a water fountain or on a spray of water, the same beautiful rainbow colors may be seen. Colored effects are often produced when sunlight or sky-light falls on certain objects. Among these are thin soap bubbles, oil films on water, wings of certain insects, sea shells and pearls.

The colors described above are all reflected to the eye after sunlight, which is white light, strikes certain objects. It would seem, therefore, that light from the sun consists of these colors in the first place; and that somehow this light can be separated into colored lights. Let us see how this may be done.

Procure a glass prism and hold it in the path of a sunbeam. We have already learned that the path of a ray of light is bent twice by a prism; once upon entering the prism and again upon leaving. If that is all that happens to the light, then the bent ray would eventually strike the wall and form a white spot of light. However, the spot of light on the wall is a band of colors. If you examine the band, all the rainbow colors are found to be present. As the scientist puts it, the prism forms a *spectrum* of colors on the wall. See figure 73. The colors are red, orange, yellow, green, blue, indigo and violet, and they shade gradually into one another. In fact, the shading is so fine that it is difficult to determine where one color ends and another begins. If each shade is given a name, then the spectrum could be said to be composed of many more than the seven colors mentioned. The spreading action of a prism is explained by the fact that the different colors in white light are bent different amounts. The violet light is bent most and the red least.

If glass can bend different colored lights so as to separate them out from a beam of white light, then other transparent substances can do likewise. See page 23. A drop of rain is transparent to light and can bend the different colored rays in white sunshine. The rainbow colors are produced by falling drops of rain. When the sun is at a certain height in the sky and the raindrops are falling



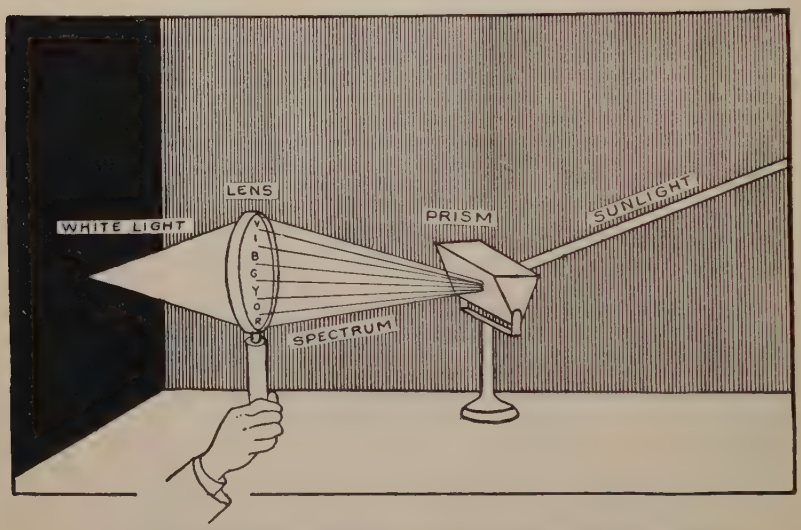
73. Prism spreads beam of sunlight into spectrum.

through a definite region, the rays of light are bent, spread out into their colors, and reflected to the eyes of a person on the ground who has his back to the sun. The raindrops spread the rays all the time as they fall, but only at a certain height are they in the position to send the colored rays to a person's eyes. That is why rainbows are rarely seen. It is not often that the sun, raindrops and eyes are all in proper position.

In the case of the moon halo, moisture particles in the air produce in a similar manner the colored ring around the moon. The same explanation serves for the rainbow colors in a playing fountain or in the ocean spray. The colors in oil films, in pearls and in insect wings are explained in a quite different manner, too complicated to consider at the present.

2. The effect on the eye of all the spectrum colors combined is to produce white

Hold a glass prism in the path of a sunbeam so as to form a spectrum band on a screen. See figure 73. Now hold a reading-glass lens in the path of the colored rays and focus them on the screen. See figure 74. What color is the focused spot on the



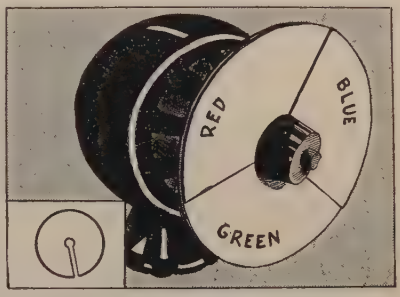
74. Convex lens focuses spectrum colors into spot of white light.

screen? Is it white? It would seem from this experiment that not only may white light be separated into the spectrum colors, but that the latter may be bent back again so as to produce white light once more.

An interesting device with which to study the effect of combining different colored rays is the rotating color disks. You can make one by cutting several different colored circles of paper as shown in figure 75. Mount them, overlapped, on a small motor shaft. When the disk rotates very rapidly, you do not see the separate colors, but rather their combined effect. By rotating the proper combination of colors a grayish white may be obtained.

You may have wondered why clear ocean water may be beaten up by the wind until it is frothy white foam. This is explained as

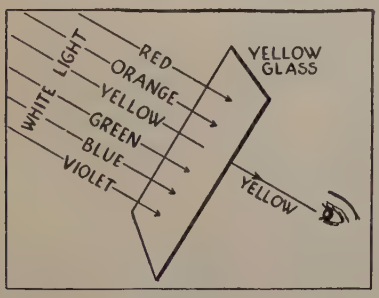
follows: When white light strikes the more or less still water, most of it is absorbed. Only a few green rays may be reflected to the eye so that the water looks greenish. However, the wind breaks up the water into millions of small particles. Each particle acts as a reflector, reflecting to the eye all the colors which strike it. To the eye, therefore, the water then appears white. In the same way we can explain the different appearance of ice and snow. The ice is transparent to most of the rays which strike it. Snow, however, is so large a mass of small crystals, that it reflects rather than transmits the light which falls on it. Hence snow appears white.



75. Method of combining colored rays.

3. A colored transparent substance transmits light of no other color than its own

Have you ever looked through sun-glasses? Such glasses are often used at the beach wherever the sunlight is too intense. They consist of two pieces of colored glass held in a spectacle frame and worn like eye-glasses. Everything appears colored through these glasses and the color depends on the color of the glass. Red sun-glasses would make everything look red. Blue glasses would make everything appear blue. Most frequently they are a yellowish brown.



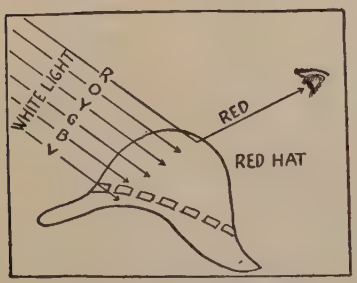
76. Only yellow light is transmitted.

When white light falls on brown glass, most of the colors are absorbed. Only the brown is transmitted. If the glass be blue, the blue light is transmitted. And so on. This idea is made use of in the theatre when colored spotlights are thrown on the stage. A

sheet of colored gelatin is placed in front of the source of white light. All the colored rays are absorbed except those which are the same color as the gelatin sheet.

4. A colored opaque substance reflects light of no other color than its own

A red piece of cloth looks red because it reflects red light to the eye. All the other colors in a beam of white light which falls on it are absorbed. In a similar way, a blue object absorbs all colors but blue, which it reflects. Other colors do likewise.

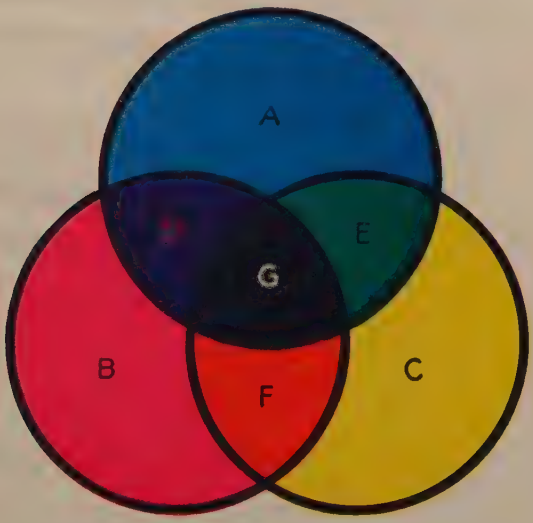


77. Only red light is reflected.

During the World War, when it became necessary to hide the location of cannon from the sight of enemy airplanes, an attempt was made to paint the guns the color of grass and leaves. In this way, it was believed that the guns would be merged into their background and become invisible. When scientists tried to find out just what color grass and leaves are, they discovered that there was more than green in growing plants. Red, brown and one or two other colors were mixed with the green.[1] They therefore painted the cannon with splotches of all the different colors present in green plants. From a high elevation an aviator saw the light reflected from each of the splotches of color. Each splotch reflected light of a color the same as its own, and the effect on the eyes of the aviator was the combined effect of all the colors. Hence he saw the cannon as a grass-green mass, no different from its surroundings. It was *camouflaged*, that is, not distinguishable. Ships on the ocean were also camouflaged by a similar method so as to make them indistinguishable from the gray sky and green ocean, when viewed at a distance through the periscope of an enemy submarine.

[1] One proof that leaves are red as well as green is the fact that many leaves turn that color in the fall, when the growth of the plant slows up and the green disappears.

78. Combining different colored rays of light.



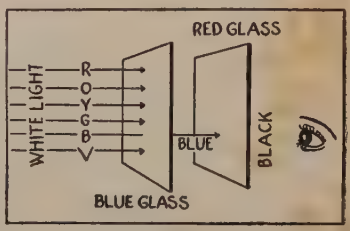
79. Mixing different colored pigments.

5. When no light reaches the eye from or through a body, that body appears black

Just as white is the combined effect of all colors of the spectrum, so black is the effect when no colors at all reach the eye. A body is black when no light comes from it. If the blackboard were perfectly black it could not be seen. The white or colored chalk-marks do reflect light and *are* seen. With the room perfectly dark, no light could fall on the chalk and nothing would be visible.

6. Combinations of a few primary colors can produce nearly all the other colors

According to a theory which scientists have concerning the eye and the manner in which the retina and brain act to produce vision, the eye can respond to only three colors of light. These are red light, green light and violet-blue light. All the other colors which we see are the effect of mixing the three primary colors. In figure 78 you see three colored circles superimposed. At point 1 you see red. At point 2 you see green. At point 3 you see violet-blue. Point 4 is a combination of red and green light and gives the sensation of yellow. At point 5 the combination is purple, at point 6 the combination is blue-green and at point 7 the combination produces white. Other shades and hues may be produced by varying the combinations.



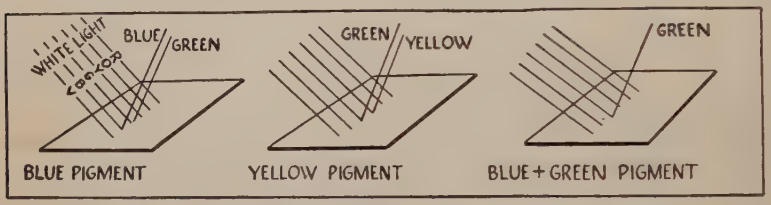
80. Blue light is absorbed by red glass.

Now, the above description holds for the mixing of light rays which have been transmitted by transparent bodies. When colors are viewed as light reflected from opaque bodies, a different method of mixing and of color effects must be explained.

In figure 79, the three colored circles are blue-green, purple and yellow. These are the primary colors used in mixing paints and pigments for covering opaque bodies. Again, different combinations may produce nearly all the shades and tints which the eye can recognize. Point *A* is blue-green, *B* is purple and *C* is yellow.

D, a mixture of purple and blue-green, appears violet-blue; *E* a mixture of blue-green and yellow, appears green. *F*, a mixture of purple and yellow, appears red. *G*, a mixture of all, appears black, since the pigments in this case absorb all the light which falls on them.

Since pigments used in painting and printing are impure, a yellow pigment usually has some green in it. A blue also has some green in it. If both blue and yellow pigments are applied on one surface,



81. Why mixing blue and yellow pigments gives green.

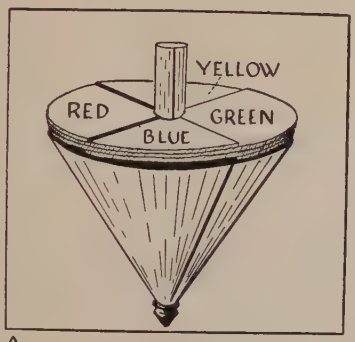
the yellow and blue are absorbed, leaving only the green to be reflected from the surface. Hence blue and yellow pigments mix as green. See figure 81.

When pictures of many colors are printed in books, magazines, or pamphlets, the same plate is put through the press several times. At each printing another color is added in its proper position. In this way each color may register by itself on the white paper and may contribute its share in producing mixtures of colors. Figures 78 and 79 were put through the press four times.

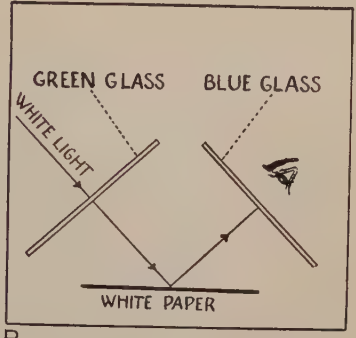
HOW MUCH DO I REMEMBER?

Pick out the correct answer for each of the statements below. Write your answers on a sheet of paper so as not to mar the book.

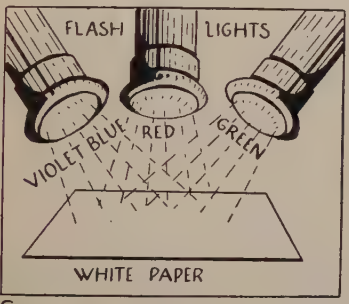
1. It is necessary to match two objects of different shades of yellow. The worst light in which to do this is (blue, green, yellow).
2. Color blindness exists among (some humans, all animals, no animals).
3. Color has (no, little, great) effect in attracting people to theatres, stores, magazines, etc.
4. A lady dressed in red will appear to be dressed in (red, black, white, blue) when flooded in blue light.
5. Sunlight is (white, bluish, yellow).
6. The spreading of sunlight by (the air, raindrops in the air, reflection from the moon) is the cause of the rainbow.



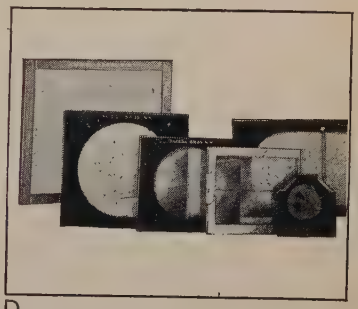
A



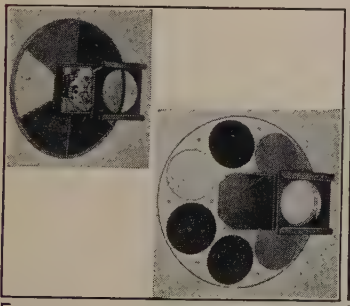
B



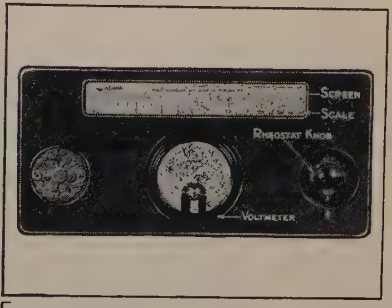
C



D



E



F

A. Make this color-top and study the effect of combining different colors.
B. What color will the eye see?
C. What color will the paper seem in this light?
D. Frames of colored gelatin. How and where are these used?
E. A color-wheel attached to a projector. How and where is it used?
F. This is known as a foot-candle meter. Find out its purpose.

7. The sun's spectrum is composed of (5, 7, 9) colors which (are distinct, gradually shade into each other).
8. The shades and hues that can be picked out from the sun's spectrum are (5, 7, 9, many) in number.
9. A glass prism bends violet light (more than, less than, as much as) it does red light.
10. The colors produced (by ocean spray, in the moon's halo, by an oil film) and the rainbow colors cannot be explained in the same way.
11. The spectrum colors (can, cannot) be combined to form white.
12. The rotating color wheel is used to (mix, separate) different colors.
13. A blue glass transmits chiefly (blue, white, yellow) light.
14. A blue light seen through a red glass will appear (blue, red, white, black).
15. A red piece of cloth reflects only (white, blue, red) light.
16. The few colors which can be combined to produce nearly all other colors are called the (spectrum, primary, rainbow) colors.
17. The three primary colors in the mixing of paints are (red, purple, blue-green, violet-blue, green, yellow).

THINGS TO THINK ABOUT AND READ ABOUT

1. Color photography and printing.
   Book O, page 1172; Book P, pages 2656, 2664; Book K, pages 289, 382.
2. You learned in this chapter, that a glass prism can spread out sunlight into a band of colors. An instrument in which such a spectrum is projected on a screen is called a *spectroscope*. The spectroscope can form a spectrum not only of sunlight but of any light. Of course, any light will not give the rainbow colors, but only those colors of which it is composed. The spectroscope has proved to be a very valuable instrument in science. Chemists have learned that they can recognize any element if they examine the spectrum of the light which it sends out when it is made extremely hot. In this way they can not only recognize unknown chemicals but they can also determine the elements which are present on distant stars and planets. We heard recently of a scientist who, with the aid of the spectroscope, found a certain vitamin in spinach juice. This is only one of the many ways in which this instrument is being used. Read how astronomers use the spectroscope, Book O, pages 2972, 3311–3314, 3343; Book P, pages 2039–2040, 3226, 4021–4029, 4342, 4493–4495, 5172–5173.
3. You learned in this chapter that cannon were camouflaged during the World War. Certain animals, especially insects, which are being constantly sought for food by other animals, are naturally camouflaged. The green grasshopper cannot be seen easily in his surroundings. The reddish lobster cannot be distinguished when he slides under the rocks. This protection is called "protective coloration." Read more about it. It is interesting to know, also, that some forms of life are colored so as to attract attention. The brilliantly red rose is not hard to find, and

so the bee flies toward it. For the rose, this is a great advantage; because the bee helps it to reproduce by spreading its pollen.
Book O, pages 2923–2926; Book P, pages 3584, 4054, 4203.

4. Paints and varnishes consist of two parts—the pigment or coloring matter, and the vehicle; that is, the liquid in which the pigment is suspended. In some paints the vehicle is water. In others, an oil is the vehicle. These are called oil paints. Linseed oil is used because it dries into a hard, waterproof surface. Pigments come from various sources. Some are chemicals, some come from certain plants or animals, and many are produced from coal tar. Read more about this, and also about the manufacture of various kinds of ink, in
Book O, pages 1779–1780, 2047, 2642.
5. A pearl is formed within the shells of certain mollusks. If a grain of sand or other material gets into the shell and irritates the soft tissue of the animal, the latter covers it with the smooth deposit of pearl. Pearls are valuable because of their many-colored rainbow appearance. These color effects are also present in mother-of-pearl, the smooth inner surface of the shells. This is used in making buttons, knife-handles, and other similar articles. Read
Book O, pages 2703, 3201; Book P, page 4591; Book K, page 385.
6. Soap bubbles in the study of light.
Book O, pages 2477, 3267–3268; Book P, page 5144.

THINGS TO DO AND MAKE

1. Experiments with colored light.
Book A, pages 114, 116; Book B, pages 217–219; Book D, pages 127–131.
2. Experiments with mixing colors.
Book I, pages 95–99.
3. Making a color top.
Book E, pages 279–280; Book G, pages 316–317.
4. The color top for matching of tints.
Book C, pages 294–295.
5. Making color discs for the phonograph.
Book G, pages 311–312.
6. Experiments with colors, pigments and paints.
Book D, pages 298–304.
7. Experimenting with colors in a room.
Book A, page 141.
8. A changing devil, a tri-colored star and other color tricks.
Book I, pages 99–101.
9. Making and experimenting with a spectrum.
Book E, pages 274–278; Book I, pages 89–95.
10. Blowing colored soap bubbles.
Book B, pages 84–86.

CHAPTER VII

GRAVITY

"Suppose a hole were bored clear through the earth."

"But it couldn't be done. You know as well as I that the deepest mine does not go down farther than two or three miles."

"Yes, I know. But can't you use your imagination? Can't you suppose that in some way some one has been able to overcome the terrific heat of the earth's interior; and that with plenty of time and money he has succeeded in boring down for a distance of 8,000 miles?"

"All right, go ahead with your fairy-tale."

"I know how hard it is to bore such a hole. Perhaps it is impossible. No one knows how many difficulties, other than the one of heat, would be encountered. But what I'm getting at is what would happen if some one stumbled into such a hole?"

"Why, he'd fall in, of course."

"Yes, but how far down would he go? This hole has no bottom. It goes clear through the centre of the earth and ends in Australia, perhaps. There the people would see a hole in the ground exactly like ours. They too would fall in. Would they fall *up* to us? Would we fall *down* to them? Or, would we fall *up* to them and they *down* to us?"

"Wait a minute, this is getting complicated. I believe that a body dropped into such a hole would fall to the centre of the earth. Didn't we learn in school that the earth attracts things towards its centre? That means, I suppose, that a man falling into the open shaft at our end, and another falling into the opening in Australia, would both drop towards each other. After each had travelled 4,000 miles, they would meet at the centre of the earth."

"That's so. Now, suppose that only one man started to fall. The further he fell the greater would be his speed. He'd be moving pretty rapidly after a mile or so. By the time he reached the centre of the earth his velocity would be tremendous. Do you think he would suddenly stop at the centre?"

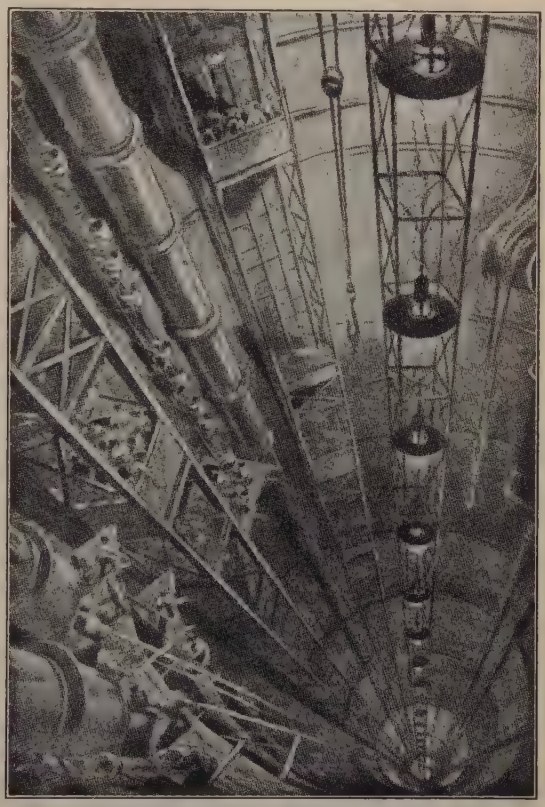
"No, I guess not."

"He would probably go right on. His speed would carry him on, but the moment he passed the earth's centre, the force of gravity would begin to slow up his speed."

"That's right; and there is no good reason why his speed should not decrease at the same rate as it increased during the first half of the trip. So that by the time he reached the surface in Australia, he would slow down to no speed at all."

"Yes, and if he had had the sense to do a somersault while falling, he could reach up, grab at something and pull himself out in Australia."

"If he didn't grab hold, he'd fall in again. His speed would increase until he reached the earth's centre, he'd shoot by the centre; his speed would then decrease until he reached the opening from which he started."



83. A scientist's plan to pierce the earth.

"I hope he'd have better luck in catching on to something this time."

"Perhaps he would, but you mustn't forget about friction. While falling, he might rub against the sides of the shaft occasionally. Then, too, the air would resist his motion. And by the way, the air at the centre of the earth would certainly be more

compressed than it is at the surface. It might be as dense as a solid. Such air would slow him up considerably, if it didn't kill him. At any rate, he might not quite reach Australia when starting from our end of the shaft."

"On the return trip, he would hardly reach his starting point. Poor man!"

"Yes. Do you know what such a man reminds me of? A pendulum! He would swing back and forth, back and forth; each swing shorter than the one before. Finally, he would come to rest at the centre of the earth."

1. Gravity pulls all bodies toward the centre of the earth

The two boys, whose conversation you have just read, were using their imagination, but they showed that they were familiar with one of the world's greatest ideas. Gravity is a force. It can make bodies move. See page 2.

Though it is believed that the force of gravity has been acting ever since the universe came into being, men did not understand or know about it until the 17th century. We owe to Isaac Newton our first knowledge about the force of gravity. In a work which was not equalled until Einstein published his famous theories, Newton applied the idea of gravity to the whole universe. He showed how this force explains the movements of the earth and planets around the sun, and of the moon around the earth. "All bodies in space," he said, "attract each other. The strength of the attraction in the case of any two bodies, depends on two things: the size of the masses and the distance between them."

Newton's law of gravitation holds for all bodies. The minutest speck of dust is attracted to the earth; and so is the largest mountain. On the one the force of gravity is small, since the mass of a dust particle is small. On the other the force of gravity is large, for a mountain has great mass. Consider a ball which you hold in your hand. There is a gravitational force between the earth and the ball, and between your body and the ball. If you release the ball, it falls to the earth and not to your body. Why? Because the gravitational attraction between earth and ball is so much greater than between your body and the ball. The mass of the earth is greater than the mass of your body.

2. Gravity is ever acting

So far as we know, no one has ever pushed a book off a table, without its falling to the floor. No aviator has ever jumped from an airplane in flight, without dropping toward the ground. "Whatever goes up must come down," shouts a boy, as he throws his hat up into the air. The boy is expressing his absolute confidence in the law of gravitation. He knows that the force of gravity is ever acting.

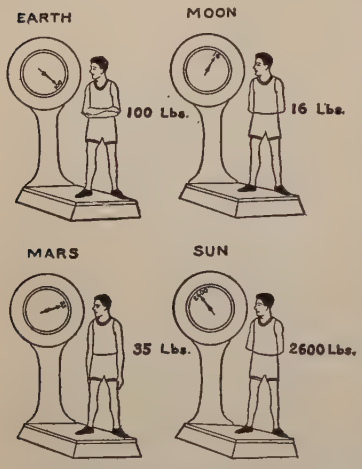
84. Gravity is ever acting.

But sometimes bodies do not fall. Is gravity acting on a book which is resting on the table? It is, but the book does not fall because the table is exerting an opposing force to support the book. Remove the part of the table under the book and the latter falls to the floor. Or, let the book be massive enough and it may break the table down. A balloon floats in the air with no visible means of support, but the force of gravity is acting on it all the time. The buoyant force of the air is overcoming the force of gravity. A tiny speck of dust or moisture floats in the air. Here too, there is a force which is opposing the force of gravity. This time it is the force of friction acting between dust or moisture particle and the air. In short, the force of gravity is always acting, but we may oppose its action with other forces.

3. The weight of a body is a measure of the force of gravity acting on it

A man once wrote a story about an imaginary trip to the moon. In describing his experiences he emphasized the fact that everything seemed to weigh so little on the moon. Stones which he could

not budge on the earth were lifted by him with the greatest ease. In walking he seemed to be wearing Seven League Boots, for each step covered a distance of several yards. He could jump six times as high as he could on the earth and he could throw objects six times as far. He explained these strange experiences by the fact that the moon's mass was only $\frac{1}{6}$th that of the earth. This made the force of gravity on the moon $\frac{1}{6}$th that of the gravitational force on the earth.



85. Weight depends upon the pull of gravity.

Your weight is the force of attraction of the earth on your body. Anything which changes the strength of this attraction changes the weight of your body. Thus, by going to the top of a tall mountain, you increase the distance between the centre of the earth and your body. At an elevation of 3 miles your body loses about an ounce in weight.

4. The effects of gravity are observable in many common phenomena

15-TON STEAM ROLLER RUNS AWAY ON HILL[1]

Milburn, N. J.—A fifteen-ton steam roller which was being driven up a hill got beyond control of its driver. It rolled backward down the hill, picking up speed. Soon it was thundering along at a speed of 45 miles an hour bearing down with irresistible force on everything in its path.

When the machine rolled into Main Street, matters became more serious, for this was a main artery of traffic. The policeman on duty had just set the "Stop" signal against the road from which the roller was coming, but one look at the rumbling monster changed his mind. He decided that there was no use in trying to argue with the driver, so he swung round the "Go" sign and gave the roller the right of way.

Without the slightest pause the machine rolled on. A little way down the street, sat a police sergeant in an automobile. The officer got out, blew his

[1] Adapted from a news item in The New York Times of Jan. 17, 1930.

whistle, raised his hand, but a moment later scurried out of the path of the onrushing avalanche. Into the centre of the town rolled the mass of steel, travelling on the left side of the street and violating all speed rules. Only the noise which heralded its coming prevented several serious smash-ups. Even so, one car was demolished and another given a blow which threw the passengers from the rear into the front seat.

Finally, it mounted a sidewalk, crushing the curbstone, and headed for the corner of a building. By this time the driver had lost all power to steer. With a roar that was heard for blocks, the roller struck and turned over on its side. The corner of the house was wrecked. Broken glass, plaster, brick and other débris were strewn far and wide. The driver was not seriously injured.

86. An effect of gravity.

The above account is only one of many occurrences which illustrate the effect of the force of gravity. Other occurrences are more common, but not so striking. For instance, dust particles are constantly falling on furniture, no matter how clean the house is kept. Falling leaves, rain and snow, running streams, the collapse of weakened structures and the fall of meteorites are all indications that the force of gravity is ever acting.

5. Gravity may aid man

Below are several paragraphs and statements, in each of which is illustrated a use for the force of gravity:

(a) When reaching the down-grade, the engineer shut off the steam. The train coasted for miles without slackening its speed very much.

(b) By mounting a water wheel a half mile below the falls, the flowing stream was made to saw wood, pump water and grind wheat.

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87. Gravity may aid man.

(c) In wrecking a house, the brick and other débris are thrown into a wooden chute. The chute empties into a truck, which, when loaded, carries the materials away.

(d) In large apartment houses and office buildings, one can mail a letter at every floor. You insert the letter in a slot and it is whisked away by the force of gravity to the mail box down below.

(e) By attaching a slide from the coal wagon to the cellar window, the coal can travel directly into the bin. The driver turns a crank which tips the truck at an angle and the force of gravity pulls the last few pieces of coal downward out of the wagon.

6. Gravity may hinder man

Below are several paragraphs and statements in which are illustrated ways in which the force of gravity hinders man.

(a) Help me to lift this cake of ice to the ice-box. It is too heavy for me.

(b) There goes my collar button. I wonder where the force of gravity took it this time.

(c) This expensive vase dropped only six inches, but it was smashed to pieces.

(d) In skating, you must learn to keep your balance. You may not realize that the force of gravity is acting until you put on skates.

(e) Why spoil a beautiful auditorium with these hideous posts? They do obstruct the view, but are necessary to keep the force of gravity from pulling down the ceiling.

(f) The auto has stalled. The grade is too steep.

The greatest bridge in the world

Travel on land is faster than travel on water. Hence man builds bridges wherever possible and convenient. Across the East River in New York City there are four great bridges, each about a mile in length. The greatest bridge of all, however, is the bridge across the Hudson River—the new Hudson Bridge.

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88. Gravity may hinder man.

Now, the most important problem of all in building a bridge, is to make it strong enough to withstand the force of gravity for hundreds of years. The steel cables which hold up the Hudson Bridge can carry 350,000 tons of weight. Fourteen lanes of traffic are provided, in which travel thousands of automobiles, trucks and trains. The huge towers 635 feet tall are embedded in deep rock. In the case of one of the towers a foundation had to be laid underneath the mud of the river bed. The west ends of the cables are anchored in the rock of the Palisades. The east ends are anchored in a mountain of concrete built especially for that purpose. The bridge road hangs 200 feet high in the air.

Since the cables are depended upon to oppose the force of gravity, they are built with the greatest care. There are four 36-inch cables in the Hudson Bridge. Each cable consists of 61 strands and each strand is made up of 434 steel wires about the thickness of a lead pencil. To spin one of these cables, a travelling wheel makes 26,474 trips across the river. The wheel unrolls the wire from a reel, and lays each successive wire next to the last. When a spool of wire gives out, wire from a new spool is spliced on. After one strand is finished, the next is spliced on in the same way. Thus, the cable consists of one unbroken thread of wire. In the four main cables there are 107,000 miles of wire, enough to be wrapped four times around the earth at the equator.

In order to protect the cables from the effects of changes in

weather they are coated with zinc, and then a travelling machine crosses the river, squeezing the strands of the cable together under enormous pressure. Engineers are confident that the cables will last as long as the bridge itself, and continue to counteract a force of gravity which may be as strong as 350,000 tons.

89. The greatest bridge in the world.

HOW MUCH DO I REMEMBER?

Copy the following letters on your paper in pencil. Make changes in ink, according to directions.

A

SELDBIQ

If the earth attracts all things towards its centre, change the S to N. If not, change the S to P.

If a falling object slows down the further it falls, change the E to O. If its speed becomes greater, do not change the E. If its speed remains the same, change E to T.

If the resistance of the air can reduce the speed of a falling object, change L to W. If not, drop out L altogether.

If the swinging of a pendulum depends on gravity, drop out D altogether. If not, change it to O.

If the force of gravity has been acting only since the seventeenth century, do not change B. If it has always been acting, change B to T.

If we owe to Newton our knowledge about gravity, change I to O. If not, do not change I.

If gravitation acts only on earth, change Q to T. If everywhere in the universe, change Q to N.

Write a sentence about the word which you now have.

B

LPBESDAZQIOM

If two bodies attract each other less when their masses are greater, change L to S. If not, change L to G.

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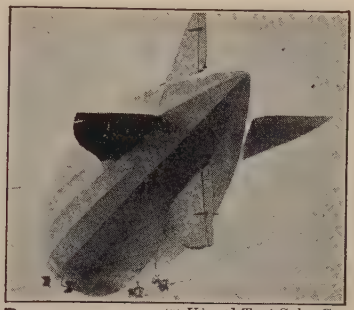
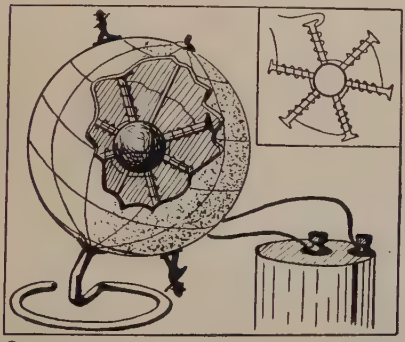
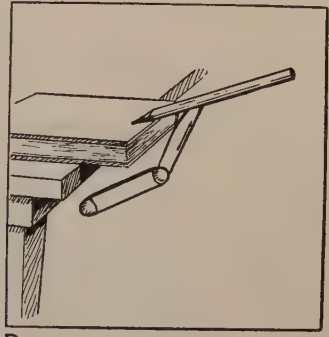


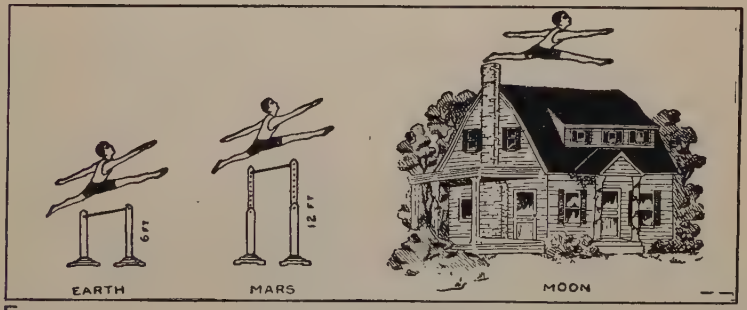
B © Visual Text Sales Co.



C



D



E

A. To what use is the force of gravity put in this picture?
B. What part does gravity play in the flight of an airship?
C. Can you mount this spindle magnet inside of a "geography" globe? The magnetic attraction will illustrate the attraction of gravity.
D. Does the pencil defy the force of gravity? Try this.
E. How far could you put an 8-pound shot on the moon? On the sun?

If the greater the distance between two bodies, the greater the attraction, change P to O. If the attraction is less, change P to R. If the attraction is the same, do not change P.

If gravity attracts neither a balloon nor a speck of dust, change B to I. If it attracts both, change B to A. If it attracts only the dust, drop B out altogether.

If a book on a table is kept from falling because the table is strong enough to oppose gravity, change E to V. If not, change to N.

If the weight of a body is a measure of the force of gravity acting on it, change S to I. If not, do not change S.

If an object weighs less at a very high elevation than at sea level, change D to T. If it weighs more, change to S. If less, change D to B.

If the gravitational pull of the moon at its surface is greater than the pull of the earth at the earth's surface, change A to I. If less, do not change A. If the same, drop out A.

If meteorites are made to fall by gravity, drop out Z. Otherwise, change Z to R.

If it is gravity which makes rivers flow, change Q to T. If not, change Q to F.

If the most important problem in building a bridge is to make it withstand the force of gravity, do not change I. Otherwise, change I to A.

If the cables of the Hudson River Bridge are anchored in a mountain of concrete on the west side, change O to P. If on the east side, do not change O. If on neither side, drop out O.

If these cables are made of solid steel, change M to T. If they are made of many steel strands, change to N. Otherwise, do not change.

What word do you now have?

C

Gravity aids man in some situations and hinders him in others. Some of the situations below are placed in the wrong column. Rearrange them on a sheet of paper, putting each in the correct column.

Gravity an Aid	*Gravity a Hindrance*
coasting of trains	wrecking houses
dropping breakables	climbing
losing things	building houses
emptying a coal truck	apartment house mail-box
carrying things	dangers of aviation
water power	falling
lifting things	slot machines

THINGS TO THINK ABOUT AND READ ABOUT

1. Has it ever occurred to you to ask how it is that astronomers can predict so accurately the movements of the sun, moon, planets and stars? Percival Lowell, the man who predicted the existence of a ninth planet, came to his conclusion after comparing the actual positions of certain

planets with the positions in which they were supposed to be. Similarly, Adams and Leverrier (see page 14) predicted the size and location of Neptune before any telescope ever sighted it. On what were the calculations of these astronomers based? The *law of gravitation*, is the answer. The position and the motion of a heavenly body depend largely upon the force of gravitational attraction. The attraction between any two bodies depends upon their size and upon how far apart they are. Now, Adams (and Leverrier, also) knew the mass of the sun and the masses of the other known planets. They knew also how far apart from each other the different bodies were. Hence, they could calculate exactly where the planet Uranus should be at any time. But Uranus never could be found where it should be according to their figures. The only way to explain this was to assume the existence of a new planet of a certain size and in a certain position. Other astronomers, directing their telescopes to that position, found the planet Neptune. You can find out more about the law of gravitation in Book O, pages 1506–1509; Book P, pages 725–733.

2. Newton and Gravitation.
   Book O, pages 239, 2476–2478, 2816; Book P, pages 164, 727, 4485–4487.
3. The words *mass* and *weight* are often used as if they mean the same thing. The mass of an object is the quantity of material in it. This is the same no matter where you take it. The weight of an object is the pull of gravity on it. It weighs less when far above the surface of the earth than it does at sea level. It weighs still less on the moon. Read more about mass and weight in
   Book O, page 1508; Book P, page 729.
4. When Galileo was 19 years of age, he was once watching a swinging chandelier in the Cathedral of Pisa. He noticed that it took as much time to complete a swing when the chandelier was moving violently as when it had almost come to a stop. He was rather puzzled by this and so he made and observed the action of many different kinds of pendulums. He discovered that the size of the pendulum bob had no effect on the number of swings in a given time. Also, it made little difference how widely the pendulum was made to swing. Only one thing seemed to decide the number of complete swings in a given time; and that was the length of the pendulum. Many years later, it was discovered that the force of gravity also affects the number of swings made in a given time. A pendulum at the top of a tall mountain, where the force of gravity is somewhat less than at the earth's surface, does not swing as frequently in the same time. Similarly, a pendulum at the north pole, which is nearer to the centre of the earth than is a point near the equator,[1] swings more frequently in a given time at the pole than it does at the equator. Now, many clocks are operated by pendulums.

[1] This is due to the fact that the earth is flattened at the poles.

They gain time or lose time, depending upon the length of their pendulums. But a clock which tells time correctly at the equator begins to "gain" as it is taken north or south, even though the length of the pendulum is kept the same. You can learn more about pendulums, clocks and the force of gravity in
Book O, pages 797–798, 801, 1391, 2715; Book P, page 5115.

5. Galileo also discovered the *law of falling bodies.* In his day, people believed that heavy objects fall to the ground faster than do light objects. Perhaps you think so too, since you have often seen a stone fall to the ground faster than a piece of paper. But that is because the air resists the movement of the paper more than it does the stone. In a vacuum, they would fall together if dropped together and they would both reach the ground at the same instant. In order to prove this fact, Galileo performed his famous experiment of dropping different weights from the top of the Leaning Tower of Pisa. He was careful, of course, to choose weights of about the same size, although one was heavier than the other. For example, a pound of feathers squeezed into a ball of the same size as is a pound of lead, would fall as rapidly as does the ball of lead. If you wish to know more about Galileo's experiments, read
Book O, pages 1391, 1392, 1508, 1509, 2190; Book P, pages 878–880.
6. At the seashore we are always impressed with the ceaseless rise and fall of the tides. About every six hours the ocean waters reach either their highest or their lowest levels. In the Bay of Fundy the difference between these two levels may be as much as 50 feet. The tides are caused by the gravitational pull of the moon. The sun is so far away that its pull is not as great as that of the moon. Why do the tides change as frequently as they do? Why are the tides sometimes higher than usual? What effect does the sun have on tides? Are there tides in the air? You will enjoy reading
Book O, pages 2323, 3496–3498; Book P, pages 1160, 1782, 1784, 1985, 2325–2328.
7. Albert Einstein.
Book O, page 2001; Book P, pages 2589–2591, 2920–2923.
8. Bridges spanning the waters.
Book O, pages 505–509; Book P, pages 1253–1272, 5028–5030; Book K, pages 467–468.

THINGS TO DO AND MAKE

1. Miscellaneous experiments with gravity.
Book D, pages 8–13; Book F, pages 124–133, 167–186.
2. Simple experiments with falling things.
Book A, pages 85–88.
3. Making a homemade roller coaster.
Book H, page 158.

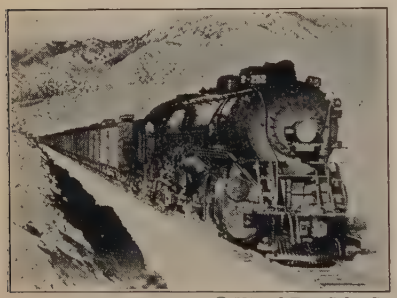
4. Experiments with the pendulum.
   Book A, pages 88–90; Book D, pages 24–28; Book E, page 101.
5. The conical pendulum.
   Book C, pages 145–147.
6. How to build a harmonograph for tracing designs with a swinging pen.
   Book E, pages 103–110.
7. The magic swingers.
   Book G, pages 320–323.
8. Experiments with scales and balances.
   Book F, pages 147–150.
9. The uncanny gas wheel. What turns it?
   Book B, pages 64–66.
10. Miscellaneous balancing tricks and paradoxes. How to balance swords, bottles, pencils, etc.
    Book A, pages 93–100; Book B, pages 3–21; Book F, pages 23–27.
11. Special balancing tricks.
    The egg that will stand up. Book F, pages 11–12.
    How to pierce a pin with a needle. Book F, pages 15–16.
    The housekeeper's terror. Book F, pages 17–18.
    The plate on the point of the needle. Book F, pages 9–10.
    The obedient and disobedient eggs. Book C, pages 74–75.
    The Sawyer doll. Book C, pages 76–80.
12. How to fill an inverted glass with wine.
    Book C, pages 99–100, 116–117; Book F, pages 28–29.
13. Halving your pear with the aid of gravity.
    Book F, pages 12–13.
14. Levelling by means of a watch.
    Book C, pages 166–167.
15. A ring rolling up an inclined plane.
    Book C, pages 82, 84–85.

CHAPTER VIII

FRICTION

Fred looked forward to his ride in a locomotive cab. He arrived at the yard an hour in advance of starting time, and while waiting for Mr. Martin to come, inquired for the whereabouts of the engine.

He found it at one end of the enclosure. A fire had already been built and its smokestack was belching forth dense clouds. At least four workmen were going over it. Each man carried a large oil can with a long spout which he was prodding into hidden and secret places of the huge machine. To reach certain parts of the interior some of the men crawled between the wheels. Oil was spread everywhere and every oil cup was filled to the brim.



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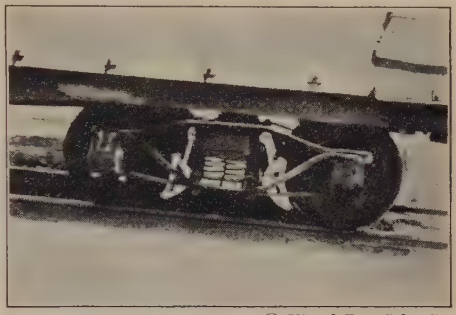
91. Overcoming friction.

"What's all this for?" asked Fred of one of the men.

"Oil makes the wheels of the world go round, my boy," was the reply.

Promptly at seven, the signal whistle sounded and the engineer turned the throttle. In a few minutes the train was gathering speed. The fireman was busy all the time, throwing on coal, watching the gauges, and shouting signals. The engineer sat calmly gazing ahead at the illuminated track. Fred was all eyes. When the train left the city lights behind, he had the strange feeling that the darkness was rushing forward to meet him. The steel monster clanked, rocked and shrieked through the night in a way that made the boy's flesh creep. Suppose something should give way. But everything seemed to go smoothly. The oil was

doing its work. When the engine reached a curve, the track seemed to end abruptly. A moment later it lurched so hard that Fred had to clutch his seat to keep from being thrown against the furnace door. At one place they seemed to be running into a hill, but before long the mouth of a tunnel enveloped the flying train, plunging everything into darkness.



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92. Friction caused by brake bands on train wheels.

It was upon emerging from this tunnel that Fred had the first of his two thrilling experiences. Suddenly, there was a shout from the engineer. "Red Eye!" he cried and pulled a cord. Fred caught a glimpse of a red signal light ahead, as the piercing shriek of applied brakes filled his ears. The train was slowing down, but it rolled along for more than a mile before stopping. They were but a hundred yards from the rear end of a freight train.

"Thank your lucky stars for the brakes, son," said the fireman to Fred. "This was certainly a close shave."

Before the train could go ahead the engineer went out to inspect the brakes. The friction had burned out the brake linings in several places. "We shall have to go easy from now on," he said.

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93. Friction built this business. Explain.

The freight train was finally sidetracked and Fred's train resumed its ride. The road now changed sharply to up-grade and, to make matters worse, an icy sleet began to fall. After several miles of this, the locomotive began to labor. The fireman heaped coal on the fire in an effort to keep the steam pressure at its maximum and the engineer opened the throttle wide. In

spite of everything, the train slowed up. Then a grinding of the locomotive wheels began. The train just crawled along. Looking out, Fred saw a stream of sparks fly from the track, where the driving wheels were slipping on the icy surface.

"Sand!" yelled the engineer. The fireman jumped at a lever and pulled hard. The sand-box was opened and its contents released on the tracks. The wheels gripped and the train jumped forward. Luckily, the crest of a hill had been reached. From then on the land sloped downward, but the engineer would not risk going at high speed. For a time they rode along at about 30 miles an hour, finally reaching their destination.

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94. Friction produces heat.

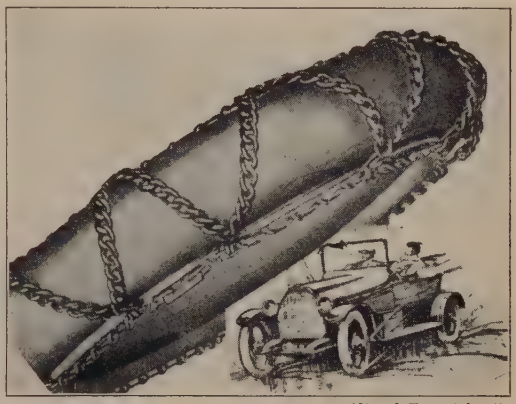
Three things stood out in Fred's mind about his eventful ride: the great quantities of oil used on the engine, the importance of brakes and the value of sand on slippery tracks.

1. Friction is the resistance caused by the rubbing of one surface against another

It takes force to rub one body over another. As we rub we overcome a resistance which we call friction.

In the story of Fred's ride in a locomotive, friction played two important parts. In the first, friction was something to be eliminated because it interfered with the movement of the engine. Every bearing, every moving part was bathed in oil, for oil clings to metal and separates rough surfaces which are in contact. In the second part, friction became desirable and necessary, in order to stop the moving train. The brakes when

jammed down on the spinning wheels brought rough surfaces together. It requires force to rub one surface against another and so the force of the moving train was called on to do the rubbing. This slowed up the train. Again, the drive-wheel of the locomotive slipped on the icy track, the surfaces in contact were too smooth to grip each other. Sand was spread in order to roughen the surfaces.



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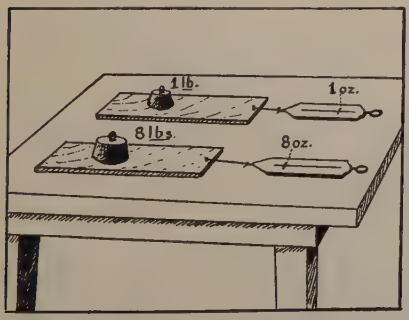
95. Friction increased by roughness of rubbing surfaces.

You will remember, too, that the brake linings were burned out. Moving surfaces in contact are always worn away. We are made aware of this when the heels and soles of our shoes need replacement. The floors and carpets on which the shoes tread also show the effect of friction.



96. Friction depends upon the pressure between the rubbing surfaces.

The constant wear and tear of objects around us is proof of the action of friction. Lead pencils become dull as they are rubbed over paper. Particles of a pencil eraser wear away with the marks we try to remove. The rubber tires of an automobile become thinner as they roll. Furniture, tools and machinery all show the effects of long usage. Even our teeth wear down from the constant friction involved in chewing food.

And yet, friction has its uses. We have already cited its use in slowing down a vehicle and in making it easy for wheels to grip the

ground. There are other values of friction. Walking would be impossible without friction, as you can perhaps realize when you think of your experiences on an icy pavement. Without friction we should find it difficult to put objects where we want them.

A body in motion would continue to move forever, if some force did not act to stop it. This force is usually friction. A wind once started would blow forever, were it not for friction; and without friction, ocean waves would never die down, the sea would never grow calm.

Filing metals and sandpapering wood are positive uses of the force of friction; as is also the process of sand-blasting. The dentist who cleans your teeth and the bootblack who polishes your shoes both make use of the force of friction as they rub one rough surface over another.

2. Friction produces heat

No doubt you have rubbed your hands together when they were cold. A brisk " rub-down " after a cold shower makes your body glow with warmth. Strike a poker sharply on a stone and sparks fly, because the heat caused by friction as the poker scrapes over the stone is sufficient to set fire to small particles of stone and iron. If you have ever sharpened a knife on a grindstone you remember the shower of sparks which leave the wheel. Bore a hole through a thick board and then touch the drill. You will probably let go to avoid scorching your hand. If you ride a bicycle or if you skate, you must know how hot the wheel bearings get, especially when they lack oil and after you have travelled some distance. When a motorist or a train engineer forgets to oil all rubbing surfaces, he is usually stopped by a burnt-out bearing.

3. Friction depends upon the roughness of the rubbing surfaces

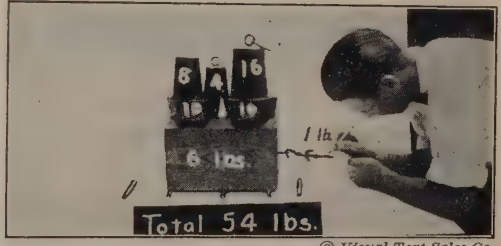
Smooth surfaces produce less friction than rough ones. Try to write with chalk on a window pane, and compare the result with chalk-writing on a blackboard. One can almost say that friction makes writing possible.

When a motorist reaches a detour sign he is usually annoyed. He knows that a rough roadway awaits him and that the friction

between wheels and road will be great. Not only is his comfort destroyed, but his tires are probably severely strained. And yet, the same man is glad to encase his tires in chains so as to avoid skidding on a wet pavement. In the latter case, he purposely roughens the surfaces of the wheels so as to increase friction.

One reason why oil reduces friction is that the oil particles fill the pits and cavities of the surfaces in contact, thereby making them smoother. Though the shaft of a machine and the bearing in which it turns are usually polished smooth, there are always many tiny rough spots which no amount of polishing can remove. Hence a film of oil between moving metal parts becomes very necessary. In effect, the oil film keeps the surfaces from touching and rubbing.

97. It takes 9 pounds to overcome the sliding friction.



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98. It takes 1 pound to overcome the rolling friction.

4. Friction depends upon the pressure between rubbing surfaces

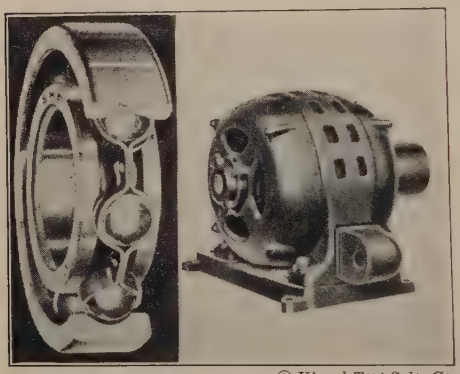
Attach a spring balance to a board and pull the latter over the table. Note what the balance reads when the board is moving. Now, add a weight to the board and repeat the observation. Add a second weight. In each case, the spring balance indicates the force of friction which must be overcome in order to keep the board moving.

It is more difficult to drag a heavy body than a light body because the heavy body presses the rubbing surfaces together more. When an automobilist jams on the brakes, he presses the

rubbing surfaces hard against each other. The emergency brakes bring greater pressure to bear than the foot brakes.

5. Rolling friction is less than sliding friction

Some of man's most important inventions are so old that we do not know how or by whom they were devised. For example, who first thought of using a wheel for minimizing friction? The wheel is so often used that it has become essential to our lives. That "the whole world moves on wheels" is a frequently heard expression.



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99. Ball bearings decrease friction.

Back in the dim and distant past we can imagine a hunter carrying home his day's catch. He grows tired, the heavy carcass of the dead animal is too much for him. For a time he finds it easier to drag the load along the ground. Then he discovers that poles placed under the weight slide along the ground more easily than does the rough animal fur. One day our hunter, returning with an unusually large catch, happens to use rather smooth round poles. Furthermore, he places them crosswise rather than lengthwise. He notices with interest how these poles roll and how easy it is to pull the load over the rollers. Though we can only guess about all this, it must have been some such experience which led a very intelligent huntsman to cut round slabs, connect their centers with what amounted to an axle and to use this crude wagon for dragging heavy loads.

Though the original inventor of the wheel did not know it, rolling friction is less than sliding friction. Not only is all land transportation dependent upon the wheel, but nearly all machines that move automatically utilize the wheel principle. Thus, even water and air transportation make use of the wheel in the engines which drive the vehicles.

An interesting comparison may be made by testing two pairs of skates, one with ball bearings and another with only a slide bearing. You know from experience of course how much better the ball-bearing skates are for riding purposes. However, determine how much longer the ball-bearing wheels turn when an equal turning force is applied to both types.

In figure 100 you see a modern type of rolling friction bearing which makes use of tapered cylinders rather than balls. These are very useful for machines carrying heavy thrust loads.

100. Roller bearings decrease friction.

HOW MUCH DO I REMEMBER?

A

Tell which statement in List X best explains each statement in List Y. Write your answers on a sheet of paper so as not to mar the book.

List Y

1. The brakes increased the resistance of friction.
2. This slowed up the train.
3. I felt warm after the "rub-down."
4. Skid chains helped the tires to get a grip on the ground.
5. The wheels of the locomotive are equipped with ball or roller bearings.
6. Oil was spread everywhere and every oil cup was filled to the brim.
7. I filed a sharp point on the nail.
8. The more we walk on the carpet, the sooner we must buy another.
9. The train was stopped by a burnt-out bearing.
10. Your machine will be more efficient if you polish these rusty parts.
11. The friction had burned out the brake linings.
12. The Boy Scout started a fire with an Indian drill.
13. A body in motion through the air or over some surface does not continue to move forever.
14. The wheels of the train became very hot.

15. The sand on the slippery track increased the wheel's grip.
16. I had to put new heels and soles on my shoes.
17. The whole world moves on wheels.
18. The rough road will ruin the tires of my car.
19. I wrote so much that I had to make a new point on my pencil.
20. The sand-blast took off the dirt from the brick wall.
21. He slipped on the ice.
22. When the train is loaded, friction is increased.
23. Sparks flew from the revolving grindstone.
24. These tires have covered hundreds of miles. No wonder they are so thin!
25. You'll be able to move that heavy case if you put rollers under it.

List X

A. Friction causes rubbing surfaces to be worn away.
B. Friction produces heat.
C. Friction depends on the roughness of the rubbing surfaces.
D. Friction depends on the pressure between the rubbing surfaces.
E. Rolling friction is less then sliding friction.
F. Friction resists motion.

B

Tell whether friction is increased or decreased by each of the following:

brakes	grindstone	ball bearings
sandpaper	wheels	skid chains
oil	Indian drill	sand on tracks
files	sand-blast	rollers

THINGS TO THINK ABOUT AND READ ABOUT

1. Since ancient times, men have been trying to invent a perpetual motion machine,—one that will run forever once it is started, and one that will require a force to start it but not to keep it going. Even to-day, the Patent Office receives plans for many such machines each year. Scientists are of the opinion, however, that perpetual motion is impossible so long as friction exists. Since we do not know how to eliminate friction entirely and since a certain amount of friction is often necessary, a frictionless machine is both impossible and undesirable. However, do not be under the impression that we should not make every effort to harness the forces of nature. It is possible to devise a machine, for example, which the moving tides would keep in perpetual motion. This is not what we mean by a perpetual motion machine, since in such case the tides would be exerting a force to keep it going. Read about perpetual motion machines in
   Book O, page 1148; Book P, pages 308, 1974.
2. From petroleum we get not only the fuel to turn the wheels of an automobile, but also the oil with which to lubricate them. When the lighter

A

B

C

D

E

F

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For each of the above, tell the following:

1. Where is the force of friction acting?
2. Which are the rubbing surfaces?
3. Is the friction useful or is it a hindrance?
4. How may the friction be increased? Decreased?

oils, such as gasoline and kerosene, are boiled off from the crude petroleum, there remain the heavier oils which are useful in eliminating friction. There are many other lubricants. From the castor bean we get castor oil, which is being used to lubricate airplane motors. Graphite, the black and soft form of carbon used in making pencils, is another good lubricant. Its flakes adhere to metal surfaces and give them great smoothness.

Book O, pages 657, 1370, 1502, 2749, 2753; Book P, page 1974.

3. In the extremely hot electric furnaces operated by Niagara's enormous power, thousands of tons of carbon (coke) and sand are fused into a substance known as *carborundum*. Carborundum is one of the hardest of all known materials; so that when it is rubbed against other softer materials the latter are worn away by friction. Thus, carborundum is an excellent abrasive for grinding and polishing metal tools and machine parts. Read
   Book O, pages 1383, 3234.
4. Electricity produced by friction.
   Book O, pages 1110–1111.
5. More about friction.
   Book O, pages 99, 1249, 1251, 2170; Book P, page 1974.
6. Smoothly polished ice skates sliding over the smooth ice! Does it surprise you that one can skate so quickly or pull a heavy sled with such ease over the ice? Read
   Book O, pages 1176–1177, 2532, 3401, 3753–3756.
7. Friction and the sand-blast. Have you ever seen window glass scratched by a sand-laden wind? Trains crossing the desert frequently return with windows etched by sandstorms. How may this idea be put to work?
   Book O, page 3123.

THINGS TO DO AND MAKE

1. Simple experiments with friction.
   Book A, pages 100–103.
2. Ways of getting a light with friction.
   Book A, pages 127–130.
3. Hints on grinding scissors.
   Book H, page 148.
4. Making an ice glider.
   Book H, pages 31–32.
5. Making an ice boat and catamaran.
   Book H, pages 27–29.
6. Making a four-passenger coasting bobsled.
   Book H, pages 24–26, 49.
7. Fresh and hard-boiled eggs.
   Book C, pages 156–157.

102. Sinking of the *Antinoë*.

CHAPTER IX

INERTIA

The tramp steamer, *Antinoë*, was sinking in a raging sea. The crew, half frozen and starving, clung desperately to the storm-swept deck. Boats were gone, engines and fires were flooded, and the rail was dipping under the waves.

Captain Fried of the United States liner, *President Roosevelt*, had picked up an S O S and was making full speed for the *Antinoë*, but the prospects of a rescue in such a storm were few indeed. There seemed to be no possibility of close approach. Oil was spread on the turbulent waters, with little result. Two of the *Roosevelt's* men attempted to launch a life-boat but were swept away by the furious waves.

"Shoot the line," he cried; and the ship was manœuvred so as to aim a small mortar at the half obscured and shadowy outlines of the *Antinoë*. In a pail by the side of the little gun was a coiled clothes line. One end of this line was fastened to the *Roosevelt* and the other end to the projectile in the muzzle of the gun. If the projectile could but shoot the line across the *Antinoë* there would be a means of sending a life-boat to the distressed seamen.

The gun boomed, but the bullet speeding from the muzzle left the rope behind. The quick, lashing jerk of the shot had snapped

the rope like so much thread. A second attempt brought the same result. Only one projectile was left. With a prayer the gunner fired the charge, but the sudden pull of the missile was too much for the rope. It snapped as before.

In despair the chief engineer worked all night, fashioning new projectiles for the gun.

The next morning, thirteen projectiles were finished. The wreck was still afloat, though it was gradually settling in the water. Ten shots were fired and every one of them tore from the line. A conference was called to discuss the baffling problem. Another whole day passed, without getting nearer to a solution. There was no let-up in the storm.

103. The rope gun.

That night, an idea occurred to the chief engineer. "It's a case of inertia," he said to the captain, "we are trying to speed up the motion of the rope too suddenly, and it can't stand the strain of the force necessary to overcome its inertia. If we can attach a spring between the bullet rod and the rope, the pull on the rope will not come suddenly. First, the spring will be stretched, and then the spring will gradually transmit the pull to the rope."

The scheme was tried. Everything was not ready until the evening of that day, but before night closed in, one of the remaining projectiles with its spring attachment was shot out from the gun. A cheer rose from the men when they saw the rope uncoil from the pail and move out with the bullet. Across the deck of the *Antinoë* slapped the rope. It grew taut—and then slackened. A jagged piece of ice had torn the line!

Sick with despair the men waited for daylight to come, for they did not dare risk the last two shots in the darkness. On the morning of the fourth day since the *Roosevelt* had arrived, the successful shot was fired. Amidst the raging tempest, a life-boat was sent out to the now exhausted seamen. Several trips were necessary for all twenty-five of them to be brought safely aboard the *Roosevelt*. The storm did not abate until the *Antinoë* had sunk, but Capt. Fried and his heroic crew steamed away with the feeling of a good job well done.

Perhaps you can remember how the whole world hailed this heroic rescue, for it happened in 1926, and how we celebrated Capt. Fried's arrival in New York City. Let us remember the event as a rescue made difficult by the law of inertia.

1. A body at rest tends to remain at rest

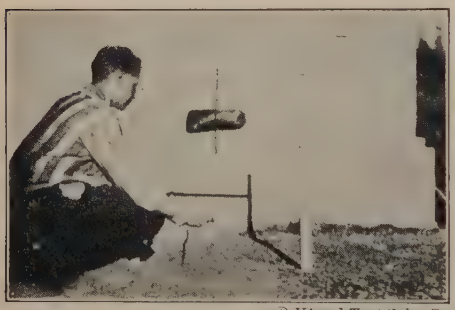
Procure a spring balance, a weight and a board, and do again the experiment described in figure 96. This time, note how many ounces' pull is registered on the balance, just before the board begins to move. The heavier the weight, the greater is the amount registered on the balance. It is evident from this experiment that a body at rest tends to remain at rest, and that a force must be exercised to overcome its tendency to remain at rest. Of course, the reading on the balance shows the amount necessary to overcome both inertia and friction. (Figure 96, page 122, tells how the amount due to friction is measured.)

If you pull on the balance quickly, the amount registered is much greater, indicating that there is a greater force of inertia to be overcome. In fact, it is the change of motion that determines the amount of inertia. By starting the weight gradually, the spring balance shows that the force of inertia to be overcome is less.

When an automobile is started its beginning speed is slow, for a large force is necessary to overcome its tendency to remain at rest. After having it in " first gear " for a while, during which time you have been giving the engine gas so as to speed it up, you shift into " second gear." This increases the speed of the car a little more. Again you feed the engine gas so as to increase the speed. Finally, you shift into " high gear." This gradual increase of speed is quite necessary, in order to overcome the

tendency of the automobile to remain at rest. Should you go at once into " high," the engine would stall. The force of inertia to be overcome would in that case be so great that the engine could not furnish a strong enough pull.

104. Slow pull causes weight to swing.



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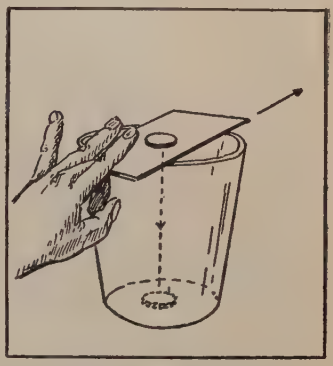
105. Sharp pull breaks lower string.

Perhaps you have been in a trolley car loaded with passengers, when the motorman has started too quickly from rest. The car jerks, a loud bang is heard from a box over the motorman's head and the lights go out. This is what has happened: the car is so heavy that its tendency to remain at rest is great. Since the motorman has tried to change too quickly from rest into rapid motion, a tremendous force is necessary to overcome the force of inertia. In order to furnish this force a large amount of current is needed by the electric motor. The large amount of current which begins to flow threatens to burn out the wires and perhaps the car too; but the circuit-breaker overhead bangs open and shuts off the power. After that, the motorman is more careful. He throws in the circuit-breaker, holds it in with his hand if necessary, and turns on the power very gradually. The car starts slowly, and as it gains speed the motorman lets go the handle of the circuit-breaker and turns on the full power for full speed.

Try this experiment: Suspend a weight as shown in figure 104. Tie a thread to the weight and pull it slowly. If you do this slowly enough you can change the weight from rest into motion

without breaking the thread. However, try to jerk the thread quickly so as to cause the weight to move suddenly. The thread snaps and the weight remains at rest See figure 105.

Another interesting experiment with the law of inertia is to rest a coin on a card laid over the top of a glass tumbler. See figure 106. Snap the card with your finger. Out it goes, but the coin stays where it was; that is, it falls into the tumbler. The trick of jerking a tablecloth from under the dishes on the table is another example of inertia. The dishes tend to remain at rest.



106. Body at rest tends to stay at rest.

Finally, consider the experience of falling backward as the train in which you are moves forward. Your inertia, that is, the tendency of your body to remain at rest, causes you to attempt to stay where you were. Were it not for the friction between your shoes and the floor, the car floor would slide along under your body, leaving you behind.

2. A body in motion tends to remain in motion

Cut away one end of a long shoe-box as shown in figure 108. Insert a rubber ball inside. Now quickly shove the box forward on the table, open end first. As you bring the box to a sudden stop, the ball keeps on going and flies out at the open end. Evidently, a body in motion tends to remain in motion.

Below are several paragraphs and statements, each of which illustrates the inertia of motion:

(a) With the report of the pistol, the runners started. Jack took the lead at once and kept it to the end. His chest broke the string at a speed which forced him to run for 20 yards before he could stop.

(b) The driver saw the child jump in front of the automobile about ten feet ahead. He jammed on his brakes immediately. However, the car had been going at such speed that it rolled

along for twenty feet. The child was struck, but not seriously injured.

(c) As the sled neared the bottom of the hill it was going at top speed. Though the road then began to slope upward, the speed carried the sled to almost the crest of the next hill, before it came to a stop.

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107. Body in motion tends to stay in motion.

(d) The second baseman leaped high and speared the line drive. The ball was moving so fast, however, that it toppled the player over backward.

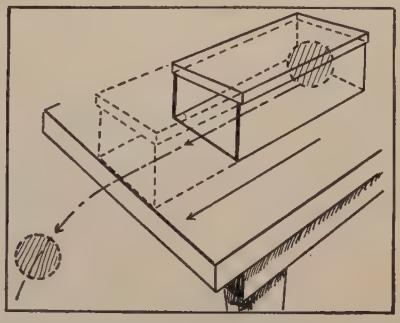
(e) The pitcher wound up and shot his arm out with the speed and force of a locomotive piston. It seemed as if his arm would fly off at the shoulder. As his arm jerked to a stop, the ball was released. It sped forward to the batter with the speed of a bullet.

3. It requires force to change the amount of motion of a body or its direction of motion

A rug full of dust is hanging on a clothes line. You wish to separate the rug from the dust. If you could push the rug forward so as to leave the dust behind, you would accomplish your purpose. You therefore grab the carpet-beater and swing it forcefully against the rug. The force of the impact is sufficient to change the rug from a state of rest to a state of motion. It moves away so quickly that the dust is left behind.

In each of the many examples of inertia described in this chapter, you will find that a force is employed every time the motion of a body is changed. From rest to motion, from slow motion to rapid motion, from motion to rest and from rapid motion to slow motion—all involve the action of a force. Without this force there would be no change in motion.

There is, however, one more case of inertia, which is sometimes difficult to understand. It has to do with a change in the direction of motion rather than its speed.



108. Body in motion tends to stay in motion.

Suppose you are in a train which is riding at a constant speed. Since there is no change in speed, no force of inertia can act. You would not know that you were in a moving train if you did not look out of the window. If the wheels were perfectly round, the tracks perfectly smooth, all sounds entirely muffled and all outside sights removed, you would think you were at home in a quiet room, provided the speed of the train does not change. Now, let the tracks curve. The moment the direction of motion changes, you feel a sidewise pull. If the change of direction is large enough, you may be thrown against the window or into the aisle. The reason for this is that your body tends to keep moving in the same direction. It takes force to change the direction and you feel that force as the train goes around a curve.[1]

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109. Inertia keeps the earth from falling into the sun.

The earth and other planets are moving around the sun at a steady speed. Their paths are nearly circular. Now in circular motion, a body changes its direction at every point in the circle. What force, then, is acting to constantly change the direction of motion of the earth and of each of the other planets? It was Isaac Newton who pointed out that it is the force of gravitation which is producing this change of direction. The force of

[1] The force which acts outward from the center of the circle in which a body is moving, is called *centrifugal force.*

attraction between the sun and each of the planets acts to change the direction of motion of the planets into a nearly circular path. Should the sun's attraction cease, each planet would shoot off into space in a straight line.

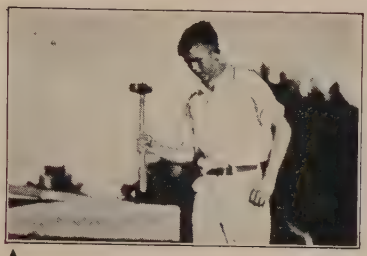
HOW MUCH DO I REMEMBER?

For each statement in List X pick out the one sentence in List Y which gives the best explanation. Write your answers on a sheet of paper so as not to mar the book.

List X

1. The train was moving very rapidly. As it slowed down, the people swayed toward the front of the train.
2. A tablecloth was jerked from under the dishes on the table without moving the dishes.
3. The trolley car was moving slowly. The motorman had to apply more power to make it move faster.
4. Should the force of gravitation cease, the earth would shoot off into space in a straight line.
5. We are trying to speed up the motion of the rope too suddenly and it cannot stand the strain.
6. As the pitcher snapped his arm forward, the ball shot out with great speed.
7. I was walking in a moving train. I fell forward when the train stopped suddenly.
8. The driver shifted his gears into "high" too quickly. The engine stalled.
9. The locomotive fireman pulled back the shovel but the coal kept moving into the fire.
10. As the train went around the curve, I felt a sidewise pull on my body.
11. The motorman turns on his power very gradually in starting the trolley car.
12. The gun boomed, but the bullet, speeding from the muzzle, left the rope behind.
13. The harness of horses that pull heavy loads sometimes breaks when the horses begin pulling.
14. An automobile is started at slow speed and this is gradually increased.
15. After it had coasted to the bottom of the hill, the sled kept on moving.
16. When the train suddenly started, I almost fell backward.
17. The cyclist stopped pedalling but the bicycle sped on.
18. As he saw his opponent gaining on him, the runner increased his efforts to run faster.
19. The runner could not stop after he had finished the race.
20. Though he jammed on the brakes quickly, the car did not stop in time.

110. PROBLEM PICTURES.

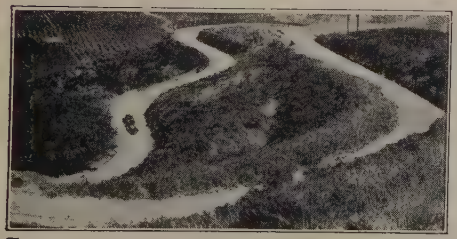


A

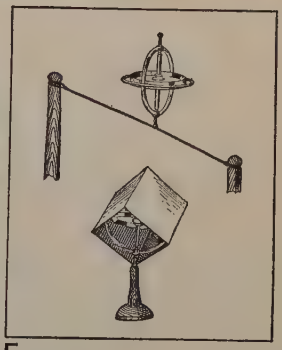
B

C

D



E



F

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For each of the above tell the following:

1. Explain the picture.
2. Is it an illustration of inertia of rest or of inertia of motion?

List Y

A. A body at rest tends to remain at rest.
B. A body in motion tends to remain in motion.
C. It requires force to increase or decrease the speed of a moving body.
D. It requires force to change the direction of a moving body.
E. The greater the change in motion to be produced, the greater is the force required.

THINGS TO THINK ABOUT AND READ ABOUT

1. Have you ever tried to swing a pail of water so that it moves around in full circles? The pail may be very much tipped or even upside down. You will be surprised to find that no water spills. Why is this? The scientist's explanation is that *centrifugal* force keeps the water in the pail, no matter what the position of the pail, so long as it is moving rapidly in a circle. In order to understand this, read again page 137. It requires a force to keep a body moving in a circle; for a circle changes its direction at every point in its course. This force is exerted toward the center of the circle in order to overcome the pull of the moving object, which is away from the center. Thus, in the case of the pail of water, the water is pulling outward from the center and against the bottom of the pail, regardless of the position of the pail. Thus, centrifugal force overcomes the force of gravity. Centrifugal force also explains why race tracks and railroad tracks are banked high around curves. Read about this in
   Book O, pages 682, 2190, 4028; Book P, pages 871–880, 3413, 1565–1566.
2. Centrifugal force is put to use in many forms of machinery. The centrifugal clothes dryer, used in laundries, is one example. The moist clothes are placed into a large vessel having small holes in its sides. As the vessel is rotated rapidly the clothes and the drops of water tend to fly out; but only the water can get through the small holes. The steam governor, which regulates the speed of steam engines, and the cream separator are other important appliances which make use of centrifugal force.
   Book O, pages 950, 1969, 3352, 3386–3388; Book K, page 190.
3. An interesting illustration of the effect of inertia on motion is the spinning top. You know how a spinning top can remain upright, defying the force of gravity. Imagine a wheel-shaped top, pivoted top and bottom inside of a framework, and rotating rapidly. The framework will have a tendency to remain in any position in which it is placed. Such a top is called a *gyroscope*. New uses for the gyroscope are being found every year. This is the instrument which stabilizes trains that move on a single track. It is this instrument which keeps ships in their course and which has made possible "blind flying" in airplanes. An aviator

cannot point his plane in a given direction and expect it to travel in that direction; for winds are always pushing the plane out of its course. The aviator must constantly steer his machine, and be guided by visible landmarks. At night or during a fog he is very much handicapped because he cannot see. The invention of the "radio beacon" has greatly aided "blind flying," but with gyroscopic equipment, the pilot need worry very little about flying a straight course. By day or night, in fog or clear air, the gyroscope keeps the plane pointed in the right direction. Airplanes are often equipped with a type of compass known as a *gyrocompass*. Read about them in

Book O, pages 1555–1556; Book P, pages 104, 534; Book K, pages 72, 74.

THINGS TO DO AND MAKE

1. Experiments with inertia, including the Japanese sword trick, the coin and the paper ring, and others.
   Book A, pages 103–107; Book C, page 135; Book D, pages 5–7.
2. Miscellaneous experiments with centrifugal force.
   Book A, pages 107–108; Book F, pages 65–66, 209–215.
3. Special centrifugal force experiments.
   The water that will not spill. Book B, pages 92–94.
   The washing out of gold. Book C, pages 108–109.
   How to free a floating cork from a knitting needle inside of a bottle. Book C, pages 160–161.
   The figure of the earth. Book C, pages 153–155.
4. Experiments with recoiling things.
   The revolving siphon. Book F, pages 51–52.
   Barker's mill. Book C, pages 151–152.
   A hydraulic turntable of nuts. Book F, pages 49–50.
   The swimming paper fishes. Book F, pages 57–58.
   The jumping pen. Book C, page 225.
5. Experiments with tops.
   Book B, pages 22–33; Book C, pages 162–163.
6. An instrument with rotating tops for recording of movements.
   Book C, pages 140–141.
7. Experiments with the gyroscope.
   Book B, pages 34–60; Book D, pages 13–17; Book E, pages 110–122.
8. How to make a motor spinner.
   Book D, pages 17–18.

111. In the beginning man used only his body.

CHAPTER X

LEVERS

We expect living things to change. One of the simplest changes is to move. All around us in life objects are moving. They move slowly and they move rapidly; they move up and they move down; they rub over each other and they collide with each other; they are constantly changing their direction of motion. Even when a body is at rest, its molecules are moving. All this motion involves forces—the forces about which we have been reading and studying in the last three chapters.

First (Chapter VII), we considered the force of *gravity*. This is the force against which we lift and climb. It is the force which determines *up* and *down*.

Second (Chapter VIII), is the force of *friction*. Against this force we struggle whenever one surface rubs against another.

Third (Chapter IX), is the force of *inertia*. We overcome this force every time we seek to change the motion of a body or its direction of motion.

In each of the chapters we learned that sometimes these forces help man to do his work and that sometimes they hinder him. At any rate, he uses them or he struggles against them with his body and with his mind.

In the beginning, man used only his body. In order to overcome the forces of gravity, friction and inertia, he exerted his muscles; but he soon found that his muscles were weak. To live comfortably and securely among the many dangers which surrounded him, he frequently needed forces far greater than his body alone could exert. Where was he to get them? Not to get them might mean suffering, hardship and death.

It was then that man began to use his mind. One by one, he began to discover ways of magnifying his bodily strength. He learned how to change small forces into large ones and large ones into small ones. In short, his intelligence led him to the making of *machines*. With a machine, he could move heavier objects than with his muscles alone; he could move them faster or more slowly, as he wished. The machine became a device by which man could exert forces conveniently and more effectively.

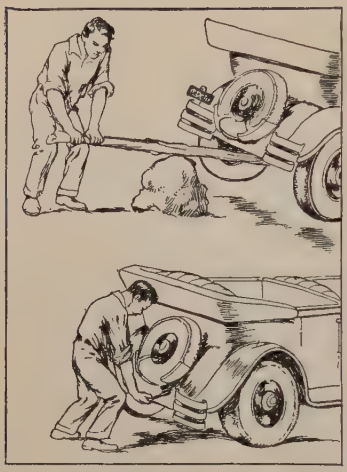
112. The lever.

To-day, we live in a "machine age." Most of the world's work is done by machine; but it took thousands of years before we developed to our present stage. To understand and appreciate such complicated machines as the steam engine and the automobile, we must begin with a study of simpler machines. This chapter and the remainder of this book deal with the subject of machines—first the simple ones and then a few of the more important complicated ones.

. . . . . .

About two thousand years ago there lived in Syracuse, a city in Greece, a man named Archimedes. He was the world's first great inventor. The king of Syracuse, Hiero by name, was discussing with Archimedes some of the latter's ideas and discoveries.

"Your Highness," said the inventor, "I am not a very strong man, but I can move any weight whatever. If there were another



113. Which method of lifting is easier?

earth on which I could stand, I could even move this earth wherever you pleased."

The king was amused, but he liked Archimedes and had respect for his great mind.

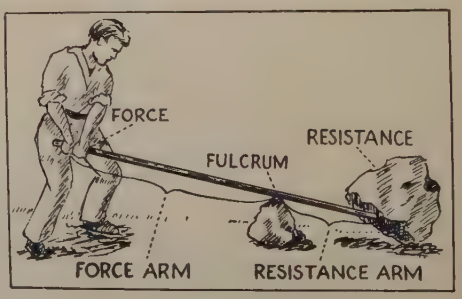
"Prove it," he said. "Move something big and heavy. One of my large galleys is several hundred yards from shore. Let me see you pull it in."

The strange thing is that Archimedes made good his boast. With levers and ropes and pulleys he not only dragged the ship toward shore, but pulled it up on the sand.

Let us study the first and most important of the simple machines —the *lever*.

1. The lever is a simple machine in which an applied force may overcome a resistance

In figure 113 you see two men, each one trying to lift the rear end of an automobile. The first is using his muscles alone and will probably fail. He may do himself some injury. The second is bound to succeed. The long pole which he is using is the lever.



114. Parts of a lever.

There are several parts to a lever. First, is the *fulcrum;* the point where the lever is pivoted or supported. Second, is the applied *force;* and third, is the *resistance* or weight to be overcome. The distance between the fulcrum and the force is known as the

force arm. The distance between the resistance and the fulcrum is known as the *resistance arm.* See figure 114.

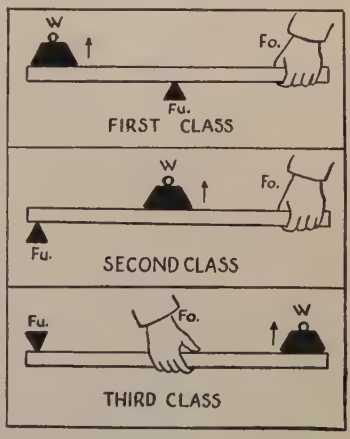
2. There are three different kinds of levers

Though all levers have the parts listed above, their locations with respect to each other are not always the same. By studying figure 115, you will find three ways of arranging fulcrum, force and resistance.

In the first, the fulcrum is between the force and the resistance. This is called a lever of the *first* class.

In the second, resistance is between the fulcrum and the force. This is called a lever of the *second* class.

In the third, the force is between the fulcrum and the resistance. This is called a lever of the *third* class.



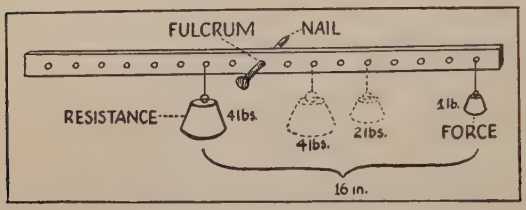
115. Three kinds of levers.

3. A first class lever is generally used to overcome a large resistance with a smaller force

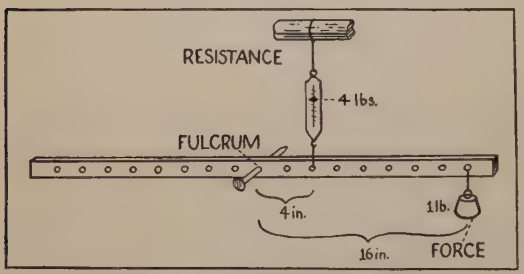
Bore a hole at each of the even numbered inch-marks on a yardstick. Insert a round nail in the hole at the 18-inch mark and support the nail so that the arrangement resembles a see-saw. See figure 116. The yardstick should balance perfectly. Hang a 4-pound weight from the hole which is 4 inches to the left of the nail. To balance the stick a 4-pound weight may be hung 4 inches to the right of the nail. But there are other ways of restoring the balance. A 2-pound weight suspended at a point 8 inches to the right will be sufficient, and also a 1-pound weight suspended at sixteen inches to the right of the nail. See the weights shown in dotted lines in figure 116.

From the above, it can be seen that a large resistance (4-pound weight) may be overcome by applying a small force (1-pound

weight). The effect of the lever, therefore, is to multiply the effort which is exerted. In figure 118 are illustrated several commonly used levers of the first class. Among these are the crowbar, the beam balance, the tack-puller, the pump-handle, the see-saw and the scissors.



116. Experimenting with a first class lever.



117. Experimenting with a second class lever.

Although the resistance overcome by every first class lever is greater than the force applied, the latter always moves through a greater distance than does the resistance. You may have noticed this fact in a see-saw, when a heavy boy balances a light boy. The latter sits farther away from the fulcrum than does the former. In this way, the small boy's weight can overcome the resistance due to the weight of the large boy; but the small boy goes up higher and faster. This fact is made use of in machines whenever it is desired to change a small amount of motion into a large amount.

4. A second class lever is also used to overcome a large resistance with a smaller force

See figure 117. In this case a 1-pound weight is suspended sixteen inches to the right of the fulcrum; and a spring balance is attached at the hole which is 4 inches to the right of the fulcrum. The upper end of the spring balance is fastened to a fixed support, as shown. Note that the balance reads about 4 pounds. The part of the yardstick to the left of the nail may be ignored in this experiment.

Considering only the right half of the yardstick, we have a lever of the second class; since the resistance is between the fulcrum and the applied force. Again a large resistance (4 pounds) has been overcome by a smaller applied force (1-pound weight).

In figure 119 are illustrated several commonly used levers of the second class. Among these are the crowbar (no. 1), the can

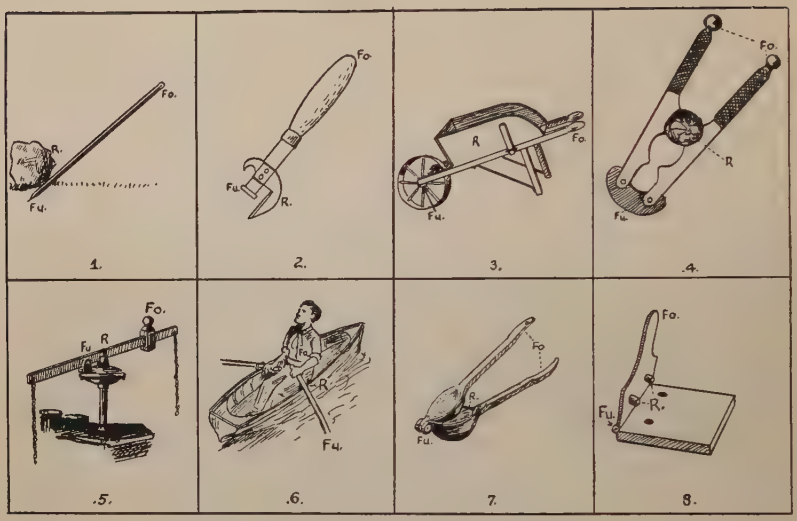
118. Some common first class levers.

opener (no. 2), the wheelbarrow (no. 3), the nutcracker (no. 4), the safety-valve in a steam boiler (no. 5), oars in a rowboat (no. 6), the lemon-squeezer (no. 7) and the hole puncher (no. 8).

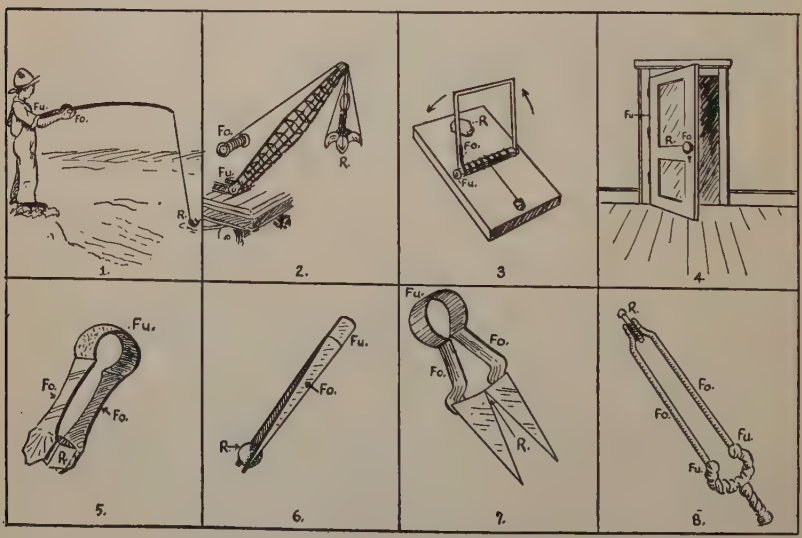
5. In a third class lever a large force moving through a short distance causes a smaller force to move through a longer distance

In a manner similar to that shown in figure 117, a 4-pound weight is suspended from the hole, 4 inches from the fulcrum. A spring balance is attached sixteen inches from the fulcrum. The balance reads about one pound. Here, too, you may ignore the part of the yardstick which is to the left of the nail.

Since the applied force is between the fulcrum and the resistance,



119. Some common second class levers.



120. Some common third class levers.

we may call this a lever of the third class. In this lever, the resistance overcome (one pound) is smaller than the force applied (4-pound weight). However, the distance through which the resistance moves is greater than that through which the force moves; as can be seen from the fact that the resistance describes a larger circle around the fulcrum as a center.

In figure 120 are illustrated several commonly used levers of the third class. Among these are a fishing rod (no. 1), derrick boom

121. The biceps-muscle as a lever.

(no. 2), a spring-trap (no. 3), opening a door (no. 4), the sugar tongs (no. 5), a pair of tweezers (no. 6), the grass shears (no. 7) and the fire tongs (no. 8).

It is interesting to note that in most of the above levers, the advantage to be had by their use is a large amount of movement on the part of the resistance. In the fishing rod, for example, one wishes to move the fish quickly out of the water. This is accomplished by moving the applied force through a short distance. In the same time that this force moves through a short distance, the resistance (the fish) moves through a much larger distance. Hence the fish is jerked quickly out of the water.

HOW MUCH DO I REMEMBER?

A

Review Chapters VII, VIII and IX before you take this test. Write your answers on a sheet of paper so as not to mar the book.

Name the force

1. Against which we lift and climb.
2. Against which we struggle whenever one surface rubs against another.

3. Which has to be overcome in order to change the motion of a body.
4. Which has to be overcome by a train only when it is going up-hill.
5. Which has to be overcome by a train always while it is moving.
6. Which has to be overcome by a train only when it starts, stops, or changes its speed or direction of motion.
7. Which causes meteorites to fall.
8. Which causes meteorites to get hot.
9. Which is helpful in starting fires.
10. Which keeps a train going after the engine has been shut off.
11. Which stops the train when the brakes are applied.
12. Which keeps all things on the earth.
13. Which prevents things from sliding too much.
14. Which causes things to wear away.
15. Which oiling helps us to overcome.
16. Which holds the earth in its path around the sun.
17. Which keeps the earth moving in that path.
18. Which causes objects to have weight.
19. Which makes things fall.
20. Which is partly overcome by the use of wheels.

B

Fill in or select the correct answer for each of the statements below. Write your answers on a sheet of paper so as not to mar the book.

1. The three great forces which are involved in all motion are ....., ... and .....
2. These forces (help, hinder, sometimes help and sometimes hinder) man.
3. ..... are devices by which man can exert forces conveniently and more effectively.
4. Archimedes moved the galley by means of (a steam engine, a gasoline engine, simple machines).
5. The (automobile, lever, steam engine) is a simple machine.
6. The parts of the lever are the ....., the force and the .....
7. The point where the lever is pivoted is called the .....
8. The resistance arm is the distance between (the force and the fulcrum, the resistance and the fulcrum, the resistance and the force).
9. There are (2, 3, 5) different types of levers.
10. If the fulcrum is between the force and the resistance, we have a lever of the ..... class.
11. If the force is between the fulcrum and the resistance, we have a lever of the ..... class.
12. If the resistance is between the force and the fulcrum, we have a lever of the ..... class.
13. The ..... class lever is *always* used to overcome a large resistance with a smaller force.
14. The ..... class lever is *generally* used to overcome a large resistance with a smaller force.

122. PROBLEM PICTURES.

For each of the above tell the following:

1. What class of lever is it?
2. Where is the fulcrum?
3. Where is the force?
4. Where is the resistance?

THINGS TO THINK ABOUT AND READ ABOUT

1. Simple modifications of the lever may be found almost everywhere. Wherever work is done, there you may expect to see the operation of levers. In the more complicated machines, however, it is not always easy to discover them. In the next chapter you will learn about a number of simple machines, which, when combined with levers, make work more convenient and efficient. In the meantime, you can read more about simple levers in
   Book O, pages 174, 2187–2188; Book P, pages 1971–1974.
2. Here are a number of problems for you to think about.
   What is the rule for finding the mechanical advantage of a lever?
   Do the foot brakes of an auto illustrate the lever principle? How?
   How would you raise a window that you were unable to push up?
   Why is it easier to shut a door by pushing against the door knob than against the part of the door near the hinges?
   Are you strong enough to hold a broom horizontally at arm's length if you grasp the handle at the end? Explain.
   Why is the monkey-wrench a useful tool?
   If you were required to lift a stone weighing 500 pounds a few inches, would you use a first class or a third class lever?
   Explain the statement, "Man is a tool-using animal."

THINGS TO DO AND MAKE

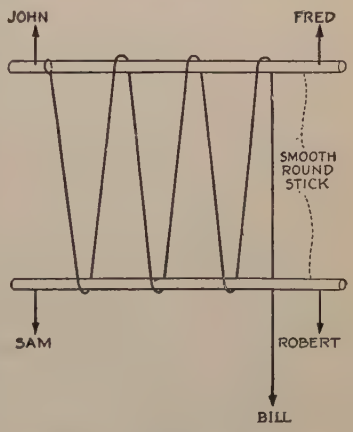
1. Experiments with levers.
   Book A, pages 90–93.
2. How to stand candles on the Christmas tree leaves.
   Book G, pages 81–82.
3. The candle see-saw.
   Book C, pages 86–87.
4. Wrestling puppets.
   Book G, pages 398–401.
5. A bottle cap lifter.
   Book H, page 195.
6. How to make a snowball thrower.
   Book H, pages 47, 48.
7. Making an instrument for recording pulse beats.
   Book C, pages 143–144.
8. A homemade tack puller.
   Book H, page 172.
9. Making a machine to test your friends' strength.
   Book G, pages 345–352.
10. Making a pantagraph with which one can enlarge or reduce pictures.
    Book B, pages 115–118; Book H, pages 142, 269; Book E, page 93.

CHAPTER XI

OTHER SIMPLE MACHINES

"Members of the Newton Science Club, I wish to demonstrate to you, how, with the aid of science, I can multiply my strength so as to beat any four of you in a tug-of-war. As you know, I am not very heavy, but I will take on the four heaviest members of the club in this match, if you will let me use my special device."

It was Bill Smith, addressing the school science club at a meeting devoted to demonstrations by its members. A ripple of laughter passed through the audience as they heard Bill's remarks, as everybody knew how poor an athlete he was. However, there had been other occasions when Bill had accomplished remarkable things with the aid of scientific knowledge. Four of the strongest boys, therefore, stepped forward to accept the challenge and the club settled back to watch the fun.

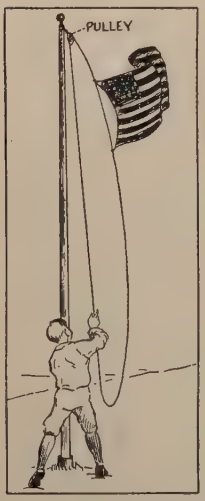


123. How the tug-of-war was arranged.

"Now, John, you and Fred hold this stick. Sam, you and Robert will please hold this second stick, facing John and Fred. (See figure 123.) I now tie an end of this clothes-line to one stick and wrap the rest of it around both sticks as follows. (See figure 123.) Brace yourselves and get ready to pull the sticks in opposite directions. I shall hold the loose end of the line and when the president gives the signal, we shall all pull. My aim will be to bring the sticks together so that your hands touch. Your aim is to separate the sticks so as to pull the rope out of my hands, if possible."

"Ready, go!" cried the president.

John, Fred, Sam and Robert pulled with all their might, but strangely enough, Bill held his own against them. For a minute, there was no movement of the sticks. Then the rope slipped a bit —in Bill's direction. At the instant of slip, Bill made a spurt, pulling harder than ever. To everyone's surprise, the sticks began to approach each other. The four boys tugged frantically; but, they were steadily losing ground. At last their hands touched; and with a last jerk which squeezed knuckles together somewhat painfully, Bill stopped and bowed to the applause of the audience.



124. A force conveniently applied.

"Now, permit me to explain how I was able to pit my strength against the strength of four combined, and win.

"When the rope passes around the smooth stick, it is in effect a pulley. Not counting the point on the stick where the rope is tied, there are therefore three pulleys on each stick. The arrangement is like a block and tackle. Let us suppose that John and Fred held the block end and that Sam and Robert held the tackle end. In that case there are 6 strands attached to the movable pulley and this gives my end a mechanical advantage of 6, not counting friction. In other words, my pulling strength on the two sticks is multiplied six times. Friction reduces it to some extent so that I can count on a pull at least five times my normal strength, against which my opponents were helpless."

. . . . . .

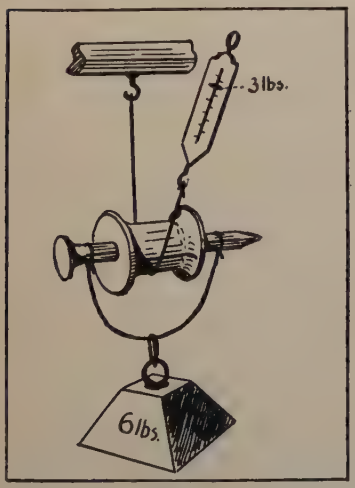
In the previous chapter we introduced you to the study of the lever, which is one of the simple machines with which man does his work. This chapter deals with several other simple machines. Like the lever they are devices with which forces may be exerted more conveniently and effectively. Among the machines to be considered are the *pulley*, the *wheel and axle*, the *inclined plane*, the *screw* and the *wedge*.

1. By means of a fixed pulley, a force may be conveniently applied

One of the most common uses of a fixed pulley is in changing the direction in which a force is applied. Have you ever raised a flag on a flagpole? You pull the rope *down* and the flag goes *up*. At the top of the pole is a fixed pulley (see figure 124), around which slips the rope. The pulley transmits the downward pull to the flag, on which it acts as an upward pull.

125. Fixed pulleys for windows.

The clothes-line is another example of the action of a fixed pulley. In this case the line passes around two pulleys, one fixed to your kitchen window and the other to the pole or fence in the back yard. Pulling the upper strand of the line toward the window causes the clothes, hanging on the lower strand, to move away from the window. Again, the fixed pulley has changed the direction in which a force acts.



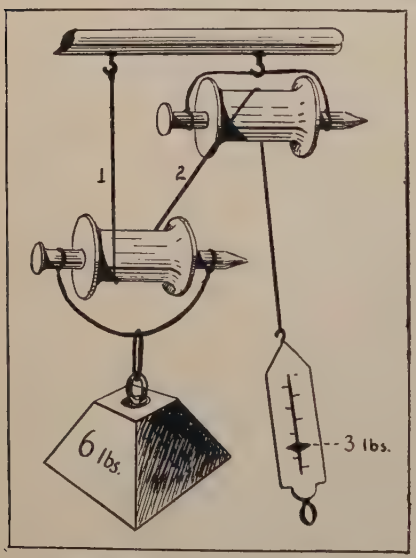
126. Experimenting with a single movable pulley.

Another interesting use of fixed pulleys is in the window sash. Figure 125 shows how the pulleys are fixed in the window frame, so that the sash is helped to go up by the hidden falling weights at the sides.

It should be noted that fixed pulleys do not increase the amount of the force exerted upon them. If anything, the force applied to a fixed pulley is somewhat reduced on account of friction at the wheel bearing. This friction may be reduced, but never eliminated entirely; so that a fixed pulley offers convenience rather than mechanical advantage.

2. By means of a movable pulley, a resistance may be overcome with less force

Bill Smith's demonstration utilized the movable pulley idea. By means of his arrangement of rope and sticks, he was able to overcome a resistance at least four times as great as his own strength.



127. One fixed and one movable pulley.

A single movable pulley may be made from a spool as shown in figure 126. Slip a nail loosely through a spool and tie a 6-pound weight to the nail, as shown. Now tie one end of a stout string to a fixed point and wrap the string around the spool. To the loose end attach a spring balance. What does the spring balance read as you pull it up to lift the weight? It reads less than 6 pounds—nearly 3 pounds, in fact. Notice that there are *two* strands attached to the pulley and that this permits a 6-pound weight to be lifted with a pull of 3 pounds. Six divided by *two* equals three.

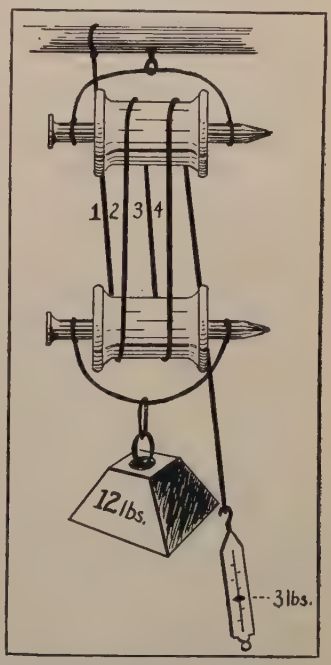
In figure 127, a single movable pulley is combined with a single fixed pulley. Again, there are *two* strands attached to the movable pulley, and again the applied force is *one-half* the resistance. The fixed pulley merely changes the direction of the applied force.

In figure 128, the spools are arranged as a block and tackle. The block consists of two movable pulleys and the tackle has two movable pulleys. In this case, *four* strands are attached to the movable pulley. Hence, the applied force is only *one-fourth* of the resistance overcome; that is, a pull of 3 pounds can lift 12 pounds.

The block and tackle is used very frequently. Pianos, safes and other heavy objects may be raised by means of this device with the

pull that only one man exerts. The great cranes and derricks which hoist steel girders into place employ the block and tackle in the same way.

When a 12-pound weight is lifted with a 3-pound pull, the spring balance moves through a greater distance than does the 12-pound weight. If the 12-pound weight should rise 5 inches, there would be a slack of 5 inches in each of four strands. Hence the spring balance moves downward for 20 inches in order to take up this slack. It is important to note, therefore, that with a block and tackle, the weight lifted is as many times greater than the force exerted, as there are strands attached to the movable pulley. Also, that the distance moved by the applied force is as many times greater than the distance moved by the resistance, as there are strands attached to the movable pulley.



128. Experimenting with a homemade block and tackle.

The above is illustrated by the procedure sometimes employed by piano movers. After attaching their block and tackle to the piano, one of the men goes up to the window of the room into which the piano is to be moved, and grabs the pulling end of the rope. He then jumps out of the window. As he drops, the piano rises; but when he reaches the ground the piano has gone up only part of the way. He repeats the process until the piano reaches the desired height. By this method, the force of gravity, rather than the man's muscles, has been used as the applied force.

Figure 129 shows how this method of piano raising is applied. In figure 130 a block and tackle is illustrated together with a hoist chain. The latter combines the pulley principle with the wheel and axle, which is explained in the next paragraph.

3. By means of a wheel and axle, a force can overcome a greater resistance or produce rapid motion

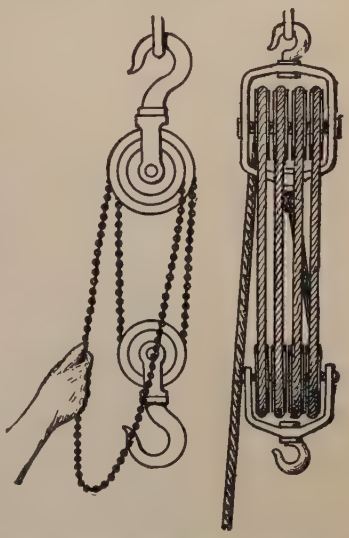
129. How a piano can be raised.

Borrow a rolling pin from the kitchen and set it up as shown in figure 131. Be sure that the rolling pin is of the kind in which the handle and the cylinder are of one piece of wood, so that they turn together. If it is of the kind in which the cylinder can rotate around the handle, insert a wedge which will jam the two and force them to turn as one piece of wood. Fasten a tack to the cylinder and suspend from it a one-pound weight at the end of a long string. Attach another string to a tack on the handle, wind a few turns on the handle and fasten the loose end of a spring balance. If the diameter of the cylinder is four times greater than the diameter of the handle where the string is attached, the spring balance will read, 4 pounds. Thus, a force of one pound applied to the wheel overcomes a resistance of 4 pounds attached to the axle.

Now, remove the spring balance and hold the loose end of the wound-up string in your hand. Pull the string so as to unwind it about two turns. What happens to the one-pound weight? It has risen quickly through a considerable distance. Thus, a force applied at the axle may produce rapid motion of the resistance attached to the wheel. The force in this case is as many times greater than the resistance, as the distance moved by the resistance is greater than that moved by the force.

Let us apply the action of the wheel and axle to a bicycle. See figure 132. As you move the pedals the sprocket wheel receives the applied force. The chain transmits this force to the axle of the rear wheel; but the diameter of the axle is usually about *one-fourth* of the diameter

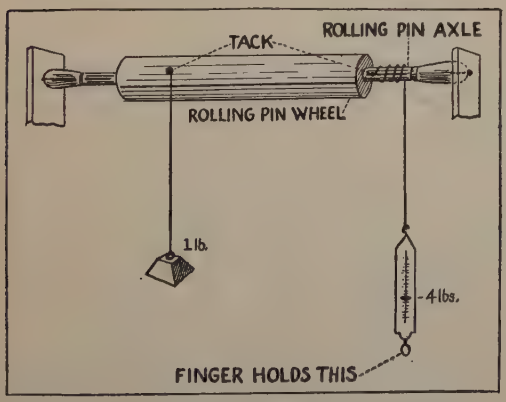
of the sprocket wheel. Hence the axle turns about *four* times faster than the sprocket wheel. The rear wheel, which moves with the axle, makes the same number of turns per minute as does the axle, and the bicycle is driven forward at great speed. Hence, for every complete turn of the pedals, the rear wheel turns completely around four times, but the effort which your feet exert is four times as great as the resistance which the drive wheel can overcome. When the road is up-hill, the increase in resistance due to the force of gravity, is multiplied four times for your leg muscles to overcome. That is why it is so hard to ride a bicycle up-hill.



130. Hoist chain and block and tackle.

A grindstone is another example of a wheel and axle used to produce great speed. As you crank, you pull hard and rotate slowly. The stone spins around at great speed; but a slight increase in pressure at the rim of the wheel makes it almost impossible to continue cranking.

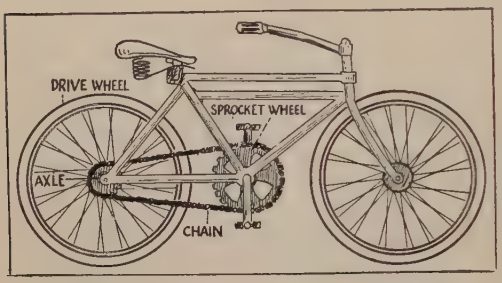
In many commonly used devices, wheels and axles are used to increase forces rather than to increase speeds. In the meat-grinder, the handle is turned rapidly through a large circle. The axle with its cutting edges rotate much more slowly but with greater force; thus chopping the meat into fine pieces.



131. Experimenting with a wheel and axle.

Did you ever notice how much harder it

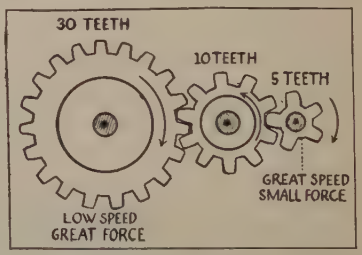
is to turn the hour-hand of a clock than the minute-hand? The minute-hand revolves twelve times as fast, and therefore it requires $\frac{1}{12}$th the force to move it.



132. Wheels and axles in a bicycle.

The steering wheel of an automobile is still another example of the wheel and axle. The force is applied at the rim of a large wheel and is moved through a large distance. This causes a small amount of motion of the front wheels against a large resistance. If you wish to realize the value of the large steering wheel, try steering the car by turning the shaft of the steering wheel with your hands. It cannot be done.

Gears are a modification of the wheel and axle. In figure 133, you see three toothed wheels arranged so that the teeth enmesh. All three wheels turn whether the force is applied to the 30-tooth wheel or to the 5-tooth wheel. However, the speeds and forces are not the same at all wheels. When the 30-tooth wheel has revolved once, the 10-tooth wheel has revolved three times and the 5-tooth wheel, 10 times. A one-pound force applied at the 5-tooth wheel becomes a two-pound force at the 10-tooth wheel and ten-pound force at the 30-tooth wheel.



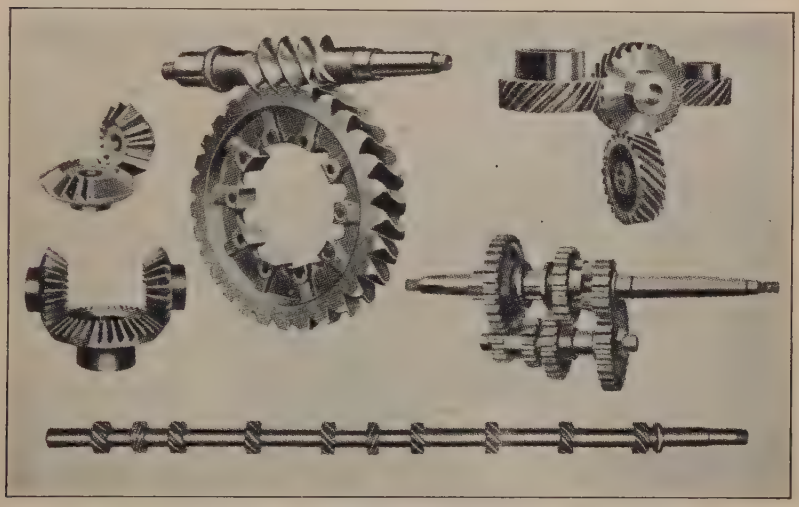
133. Gears are modified wheels and axles.

Figure 134 shows the variety of gears used nowadays in various important machines.

4. By means of an inclined plane, the resistance due to gravity may be overcome with less force

Attach a spring balance to a toy cart and drag it along. After it is moving, the balance reads an amount equal to the force

of friction which is being overcome. As you begin to drag the cart up an incline, the balance shows a greater pull, as the force of gravity is resisting the upward movement. Now lift the toy cart vertically, in order to see just how much is the pull of gravity on the cart. You will find that the balance reads a greater amount than it did on the incline. In other words, the inclined plane has made it easier to lift a weight. The more gradual the in-



134. Different kinds of gears.

cline, the less force is exerted to overcome gravity; but it takes longer to reach a desired elevation.

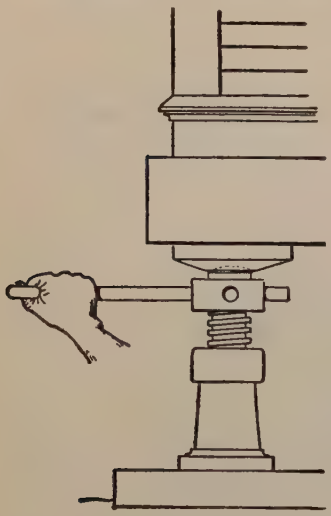
If after 25 inches of incline, there has been a rise in elevation of 5 inches, the grade of incline is called 20%; for 5 is $\frac{1}{5}$ or 20% of 25. On an inclined plane of 20% grade, the necessary pull on a body to be raised is but 20% of its weight. In other words, a wagon weighing 1,000 pounds can be pulled up a 20% grade with a pull of only 200 pounds.

Inclined planes are used very frequently. Every staircase is a modified inclined plane. How much more difficult it would be to climb steep ladders rather than stairs. We could reach our rooms more quickly with ladders, but by a greater exertion of force. The winding roadways up a mountainside are inclined planes. It

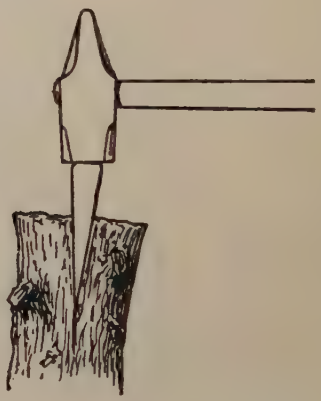
takes less force to climb these roadways than it would take to climb directly up the face of the mountain. However, we lose time.

Rolling a safe up an incline to a truck is still another instance of the use of an inclined plane.

When we descend stairs or coast down a hill, we are permitting the force of gravity to act more gradually on our bodies than it would act in a sheer drop of the same elevation. Thus, an inclined plane works both ways. It helps us to lift a body



135. A jack screw.



136. A wedge.

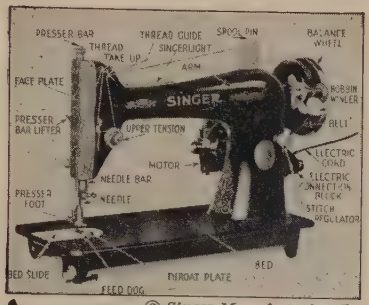
against the force of gravity with a force smaller than the body's weight and it helps us to lower bodies gradually so as to avoid too rapid a fall.

5. The screw and the wedge are simple machines whose action resembles that of the inclined plane

As is the case in all the other simple machines which we have described, the screw helps us to overcome a great resistance by the application of a smaller force. An important use of the screw is in the lifting jack which, as is shown in figure 135, can be employed to raise the side of a house.

The wedge is another form of inclined plane. Figure 136 shows how a force applied to a wedge can split a stout log. Pins, needles, spears, arrow heads, knives, chisels and many other carpenter tools are examples of the wedge.

137. PROBLEM PICTURES.



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B © *Visual Text Sales Co.*

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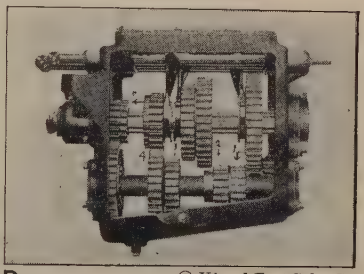

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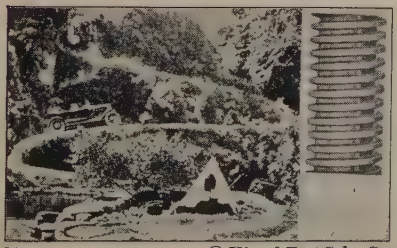

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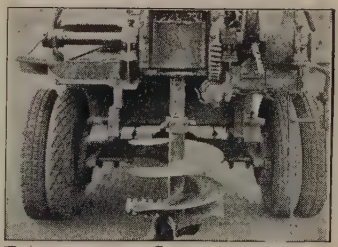

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For each of the above tell the following:

1. Name the object shown.
2. List the different simple machines you can see.
3. Describe the use of the machine illustrated.

HOW MUCH DO I REMEMBER?

Rule three columns on your paper. Head these columns as follows:

Pulleys | *Inclined Plane* | *Wheel and Axle*

As you read each of the statements below, decide upon the column or columns to which it refers. Then place its number in the proper column or columns. If a statement seems to have no relation to any column, do not list it at all.

1. A force applied to the wheel produces a rapid motion of the resistance attached to the axle.
2. It may have a 20% grade.
3. It is used to lift a flag to the top of the pole.
4. With it, forces may be exerted more conveniently and more effectively.
5. It is used to raise things up to a truck.
6. When it is movable and single, the applied force is ½ the resistance.
7. If the resistance is greater than the force, the motion of the resistance is faster than that of the force.
8. It is used in the bicycle and grindstone to produce great speed.
9. Friction reduces its mechanical advantage.
10. Its action resembles the action of a wedge.
11. Gears are a modification of it.
12. It may be either fixed or movable.
13. With it, a resistance may be overcome with less force.
14. The winding roadways of a mountainside are modifications of it.
15. When it is fixed, it does not increase the force exerted.
16. It is used in meat-grinders.
17. The weight lifted is as many times greater than the force exerted as there are supporting strands.
18. When movable, it is used to change the direction in which a force is applied.
19. Its action resembles the action of a screw.
20. It is used in the block and tackle.
21. Every staircase is a modification of it.
22. It is used on a clothes-line.
23. It is used in lifting pianos.
24. It is used when you pedal a bicycle.
25. It is used in an auto's steering wheel to overcome a large resistance with a small force.

THINGS TO THINK ABOUT AND READ ABOUT

1. More about gears.
   Book O, pages 278, 283–285; Book P, page 558; Book K, page 408.
2. More about the inclined plane.
   Book P, page 1972.
3. Hardly an invention reaches the patent office which does not embody the principle of at least one of the simple machines. Here is an interesting article on inventions called "Making the World Anew."
   Book P, pages 83–110.

4. Simple machines are combined in many ways to form complicated ones. The machine which manufactures shoes or weaves cloth is so complex that most of us do not see in it the action of levers, gears, pulleys, screws, etc. It seems like a maze of moving parts and one often wonders how the human brain can understand and control it, let alone devise it. And yet, careful observation brings to light one after another of the simple machines we have studied. Here we see a force increased by a lever, or the speed of motion increased by a wheel and axle and in another place we find the direction of a force changed by a pulley. As you turn the pages of the reference books listed below, examine the pictures of machines shown there. Try to pick out the levers, the pulleys, the gears, etc.
5. Cranes and derricks.
   Book O, page 2189; Book P, pages 102–103, 119, 120; Book K, pages 536, 543.
6. Lathes—which shape the parts of other machines, furniture, etc.
   Book P, pages 1734–1735.
7. Propellers. Most modern propellers illustrate the principle of the screw.
   Book O, pages 55, 3212–3214, 3518; Book P, page 5020.
8. Locks and keys.
   Book O, pages 2042–2043.
9. Power driven tools.
   Book O, pages 3514–3515; Book P, pages 1733–1744.
10. Sewing machines.
    Book O, pages 1688, 3186–3188; Book P, pages 2675–2688; Book K, page 279.
11. Clocks and watches.
    Book O, pages 797–803; Book P, pages 5102–5114; Book K, pages 61–71.
12. Sawmill machinery.
    Book O, pages 2080–2082, 3516; Book P, pages 4318–4321.
13. Farming machinery.
    Book O, pages 43–44, 2095, 2983, 3493–4394; Book P, pages 905–910; Book K, pages 556–574.
14. Shoe manufacturing machinery.
    Book P, pages 3515–3528; Book K, pages 436–448.
15. The talking machine.
    Book O, pages 2774–2776; Book P, pages 2901–2909; Book K, pages 43–49.
16. Printing machines.
    Book O, pages 489–463; 2472–2475; 2916; Book K, pages 172–180, 286–289.
17. Elevators and Escalators.
    Book O, page 1132; Book K, pages 232–240.
18. Calculating machines.
    Book O, pages 571–572, 653, 677; Book K, pages 345–356.

19. Dredges and steam shovels.
    Book O, pages 1039–1041.
20. Making 25,000,000 pins a year.
    Book K, pages 318–321.

THINGS TO DO AND MAKE

1. How to make wheels, gears, pulleys, etc.
   Book D, pages 46–48.
2. Experimenting with simple machines and mechanical movements.
   Book D, pages 29–51.
3. How to win a single-handed tug-of-war against four men.
   Book C, pages 164–165.
4. Tricks in tightening a tennis net.
   Book H, page 201.
5. Making a drawer that closes automatically.
   Book H, page 173.
6. Making a vegetable grinder.
   Book H, page 297.
7. An animated shooting gallery.
   Book D, pages 50–51.
8. Making a combination lock for a drawer.
   Book H, page 169.
9. How to make a lathe.
   Book H, pages 434, 447–451.
10. Making the screw water pump, invented by Archimedes.
    Book B, pages 109–110.
11. A hand propeller wheel attachment for a rowboat.
    Book H, page 413.
12. A whirligig clapper—a good Hallowe'en noisemaker.
    Book H, page 453.
13. Making a propeller for a hand-sled.
    Book H, page 335.
14. How to make a wrench for different size nuts.
    Book H, page 379.
15. A motor-driven trip hammer.
    Book B, pages 132–134.
16. How to make a flymobile.
    Book H, pages 139–140.
17. Making a machine for testing lung strength.
    Book G, pages 353–363.

CHAPTER XII

THE STEAM ENGINE

If some one were to ask, "Who invented the steam engine?" nine people out of ten would say "James Watt." It is true that Watt played a very important part in this invention, but it is most surprising to find that certain types of steam engines were in use before James Watt was born.

Few inventions have changed the world so much as has the steam engine. In this chapter we shall make a study of both the engine and how it came to be invented. However, let us pause for a while to get a picture of the development in machines just before this great engine came into being.

About 250 years ago, we were just beginning to realize the value of coal. In the mines of England one might have seen women and children toiling in dark underground passageways, hauling loads of the black fuel. Crawling on hands and knees, backs strained and muscles aching, they dragged baskets full of coal up winding stairways. The only machines in use were simple machines. Occasionally a lever, a pulley, a wheel and axle, an inclined plane, a screw or a wedge was employed to lighten the task, when human muscles proved too weak to exert the needed force.

Then came a time when these crude methods could no longer supply the demand for coal. Women and children could not drag it up fast enough. To make matters worse, the shallow mines were all exhausted, only the deep mines remained and most of them were flooded with water. An engine was sorely needed,—an engine which could do the work of men and horses, and which would be strong enough to pump out the water and to raise coal with speed from the deepest mines.

It has often been said that "necessity is the mother of invention." Four inventions were born of this great necessity. When

combined by James Watt in the first modern type of steam engine, they not only solved the problems of coal mining but began a new age of civilization—the Age of Steam.

THE AIR PUMP

We begin with the air pump because that device first demonstrated the use of a piston. Otto von Guericke, in 1650, showed how a piston in a cylinder could be made to lift several men off their feet. He did this by pumping the air out of the cylinder, thus creating a vacuum under the piston. The pressure of air then forced the piston down into the cylinder and this downward movement pulled a cord so as to lift the men.

THE GUNPOWDER ENGINE

About 30 years later, a Dutch scientist, Huyghens, repeated von Guericke's trick of lifting a heavy weight with a piston pushed down by air pressure.

"The important thing here," thought Huyghens, "is the vacuum under the piston. For this I need an air pump. But is there not another way of creating this vacuum? I wonder what a sudden explosion would do to the air in the cylinder?"

To think was to try. He made a cylinder in which gunpowder could be exploded. As the charge exploded, all the gases (including the air) escaped through a one-way valve in the side. The outside air pressure pushed the piston down into the resulting vacuum. As the piston moved down, it pulled a rope around a pulley and lifted a weight.

PAPIN'S STEAM ENGINE

Ten years after that, a French doctor, by the name of Denis Papin, heard of the gunpowder engine.

"One doesn't need gunpowder to produce a vacuum," said he. "I can boil steam in the cylinder. The steam will push out the air, and when finally it condenses, a perfect vacuum will result."

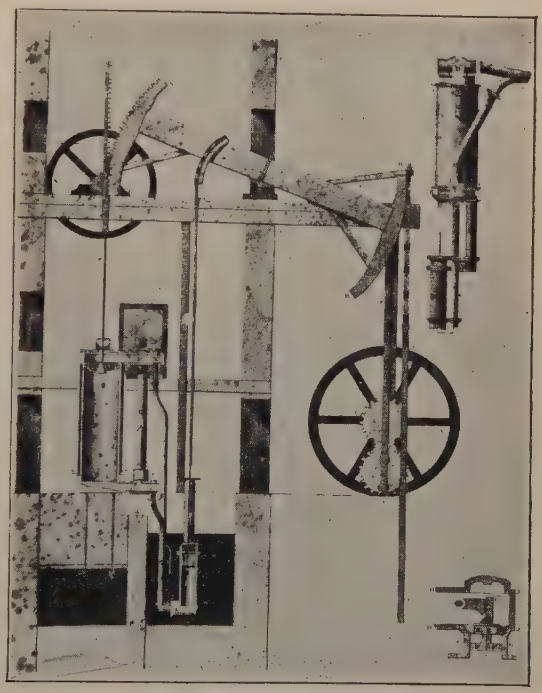
This he did. His engine acted exactly like Huyghens', but it accomplished its purpose more peacefully and more quietly.

Though the amount of useful work which Dr. Papin's engine could do was most meagre indeed, it *was*, nevertheless, a *steam engine.*

NEWCOMEN'S ENGINE

The world waited eight years for the next step. It came in 1698 with an invention by Thomas Newcomen, an Englishman.

"Papin creates a vacuum in the cylinder by boiling water into steam," he thought. "It takes time to boil and time to condense. His engine is therefore slow-acting. Why do I have to boil the water inside the cylinder, if all I want is steam? Can I not boil my water in a separate vessel? Once I have my steam—plenty of it—I can use it where I wish."



138. Watt's steam engine.

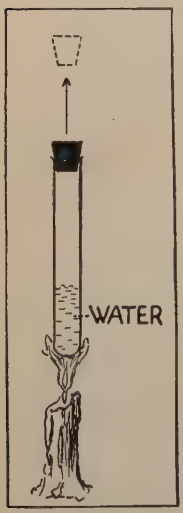
And so Newcomen built a boiler, from which ran a steam pipe to the cylinder of the engine. His engine could now make ten strokes in the same time that Papin's machine made one.

THE REAL STEAM ENGINE

There is a story that James Watt, when a small boy, stood looking at the lid on a kettle of boiling water. He noticed that the lid, though heavy, was being pushed up by the pressure of escaping

steam. The story goes on to say that this observation suggested the steam engine.

Perhaps the story is true; but it does not seem likely. When, in 1769, Watt perfected his engine, it was from von Guericke, Huyghens, Papin and Newcomen that he borrowed his ideas. He had devoted his life to the task of improving Newcomen's engine. His own fortune and that of several of his friends were spent on experimentation. Several times he almost gave up in despair, not because his idea was wrong, but because he could not make pistons and cylinders and valves that were as good as his idea.



139. Pressure exerted by confined steam.

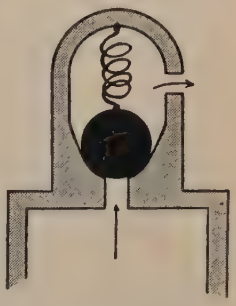
The idea was very simple. "The trouble with Newcomen's engine," said he, "is that the cylinder gets hot and then gets cold. It is hot when the steam enters and then it must get cold, so that the steam will condense. This takes time—too much time. Now, if air pressure will push the piston, why cannot steam pressure do the same? Let the steam rush in to push the piston one way, and then let it rush in on the other side to push it back. In this way the cylinder always stays hot, no time is lost, and the piston can be thrown to and fro at almost any speed, provided the steam pressure is great enough."

Watt's greatest difficulty was to fashion his materials in accordance with this idea. He had to design and build everything himself; there were no accurate instruments and tools to help him. That he finally succeeded is a tribute to his great persistence as well as to his genius.

Science has erected a perpetual monument to the memory of James Watt. It has named after him the unit of electrical power —the *watt*. Every time we pay for electrical energy we are charged at so much per *kilowatt*-hour. It is quite fitting that we should associate the idea of *power* with James Watt, for his engine has given and is giving power to the whole world. In New York City, as well as in many other places, light and power are derived almost entirely from the force of compressed steam.

1. Confined steam exerts a pressure upon the surrounding surfaces

A good way to observe the pressure of steam, when it is confined, is to boil some water in a corked test tube. See figure 139. If you do this experiment, be sure to use a strong test tube and to insert the cork *not too tightly*. When water changes into steam, it expands to about 1,600 times its former volume. Since the test tube is hardly large enough to hold all the steam, something must give way. Usually, it is the cork, which pops out and hits the ceiling.



140. How a safety-valve acts.

The boilers containing steam for steam engines are always made extremely strong. Steam is crowded into these vessels until the pressure is great—sometimes as high as 200 pounds per square inch. When allowed to escape, the steam exerts its pressure against a piston in a cylinder, in the method devised by Watt.

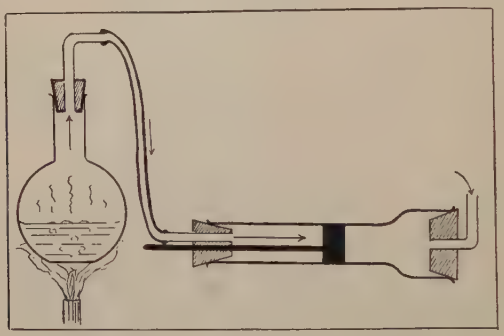
Though the boilers are strongly built there is a limit to the pressures they can withstand. Even steel rivets may be torn apart by the force of steam. In one instance described by the newspapers, an exploded boiler sent a huge fragment crashing through a brick wall and across a street. Such accidents are rare, however, because of two attachments on the boiler. One is a steam gauge which tells the engineer exactly what the pressure is at all times. The other is a safety valve which opens up automatically when the pressure rises above a certain amount. The action of such a valve is explained in figure 140. The ball which covers the boiler opening is kept in place by a spring of certain strength. As soon as the pressure exceeds the force of this spring, the ball is lifted, the excess steam escapes and the boiler is relieved.

2. In the steam engine the pressure of steam is used to push a piston

Here is an interesting way to study the action of a steam engine:

Fit a wooden rod into a one-hole rubber stopper which fits exactly inside of a tubular lamp chimney. See figure 141. In the top of

the chimney insert a two-hole stopper. One of the holes, in the centre, permits the piston rod to move freely, but not too loosely through it. To the second hole attach a glass L-tube, as shown. Another one-hole stopper, with L-tube, is inserted into the bottom of the lamp chimney. Now boil some water in a flask. When the steam is coming out with some force, lead it into the lamp chimney through one of the L-tubes. If the steam enters at one end, it pushes the piston one way ; if at the other end, it pushes the piston



141. Pressure of steam pushes a piston.

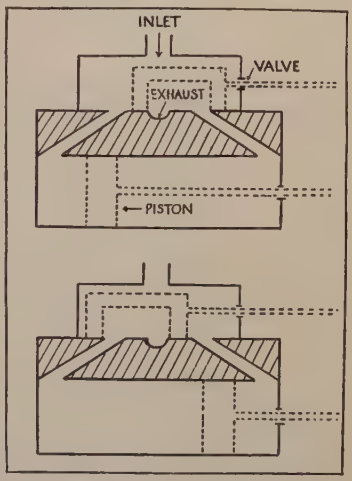
the other way. Thus, we have a shuttling piston which might do useful work if we could connect it to a crank or to some other machine. Of course, attaching and detaching the rubber tube from one L-tube to the other is slow and clumsy work. A real steam engine does this automatically, as we shall soon see.

In fact, you might at this point try to find out for yourself how this is done, by operating a toy steam engine. One of your friends or classmates surely has one.

3. Steam pushes the piston back and forth by acting first on one side of it and then on the other

The steam from the boiler enters the part of a steam engine known as the *steam chest*. Figure 142 contains diagrams showing in a general way how the steam chest is constructed. A simple way to study the action of steam on the piston is to reproduce one of these diagrams on the blackboard or on a chart. Notice that

two parts of it, V and P, are shown in dotted lines. Do not draw these on your chart. Instead, cut a piece of cardboard in the shape of V and attach it to a stick. Cut another in the shape of P and attach that to a second stick. V is known as the slide-valve and P represents the piston. Be sure that they are of such size that they fit into the diagram when laid against it.



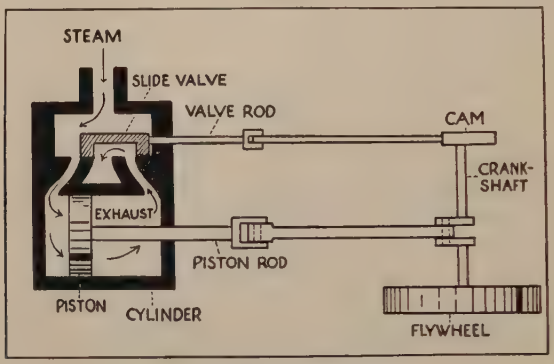
142. Steam pushes the piston back and forth.

Ask your friend to hold V against the chart in the position shown in figure 142. You hold the piston in the position indicated. Now, pretend that steam enters at the inlet. Since there is only one opening into which it can flow, it pushes its way through that opening to the cylinder. There, the piston is forced to move to the right, and so, you move the stick, sliding the piston in that direction. When the piston has moved over almost as far as it will go, let your friend move V to the left. Figure 142 shows the new positions. Now the steam must enter the opening to the right and in doing so forces the piston to return. The steam present in the cylinder from the previous stroke is pushed out under the valve, and through the exhaust.

You will find, in working with this chart, that the direction in which you move the piston depends upon how your friend moves the valve; and that the valve and piston never move together in the same direction. This may seem difficult to understand; but that is because it is harder to explain with words than with diagrams and models. Hence, we urge you to draw the diagram and to manipulate it as we described. We are quite sure that you will gain a better understanding of the steam engine in this way.

There is another part of the steam engine which is essential to the continued operation of the piston and valve. Figure 143 shows

how the piston and valve are connected to a flywheel. By means of a crank the piston turns this wheel. On the shaft of this wheel or on an extension of this shaft is another crank, to which the valve is attached. However, the two cranks are opposite each other, so that when the piston moves one way, the valve moves in the other.[1]



143. Parts of a steam engine.

The inertia of the heavy flywheel keeps both valve and piston moving steadily and smoothly.

The speed of a steam engine depends upon the amount and pressure of the steam which enters the steam chest. To control this amount a *governor* is often attached. See figure 144. The governor consists of two balls which are spun around by the motion of the flywheel. The faster the balls spin, the more they fly apart. As they separate they lift a lever which shuts off the steam. This slows down the flywheel; and therefore also the speed of the spinning balls. As the balls slow down, they drop lower and open the steam-valve a little. This, in turn, permits a faster speed. As a result, the governor keeps the engine running at a constant speed.

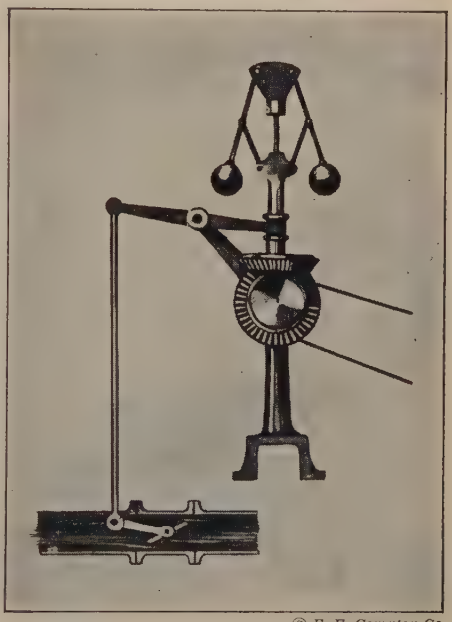
4. In a steam turbine, the pressure of the steam against the blades causes the wheel to rotate

The steam turbine is a modern style of steam engine which has some advantages over the cylinder and piston type that we have

[1] In a real steam engine, the two cranks are not quite opposite each other. They are at an angle of about 90°. The device which makes this possible is called a *cam* or an *eccentric*.

been describing. In its action it resembles a turbine water wheel, in which the pressure of water has been replaced with the pressure of steam.

Figure 145 shows a model of a steam turbine which can be easily built. The wheel is a round board to which are fastened several tin blades, set vertically. Through the centre is inserted a glass tube closed at its upper end (see insert of figure 145). A sharpened wire sticks up from a board and on this the wheel is pivoted. The glass tubing serves nicely as the bearing. When the steam from boiling water in a flask is directed against the blades the wheel spins at great speed. Figure 146 shows the rotating wheel of a steam turbine, such as is used in a modern power plant.



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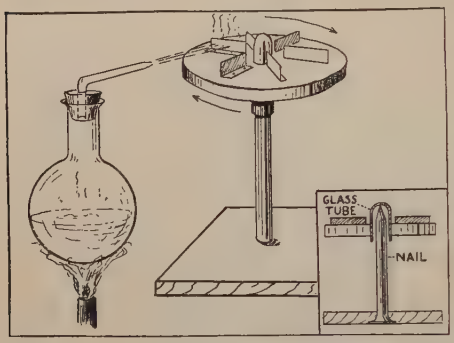
144. The steam engine governor.

5. The steam engine and steam turbine are used to do many kinds of work

One of the important differences between a civilized man and a savage is that the latter performs most of his physical work by hand, while the former uses machines. Many have called the age in which we live, the *Machine Age*. But machines must be moved; they do not turn by themselves. How, then, can they be moved? At the present time, four or five methods are employed by man. These methods are referred to as *prime movers*.

The first is the windmill, which utilizes the energy of moving air. The second is the water wheel, which takes advantage of moving

water. The third is the electric motor, which man employs whenever and wherever electrical energy is available. The fourth is the gasoline engine, about which we shall learn in the next chapter. The fifth is the steam engine.

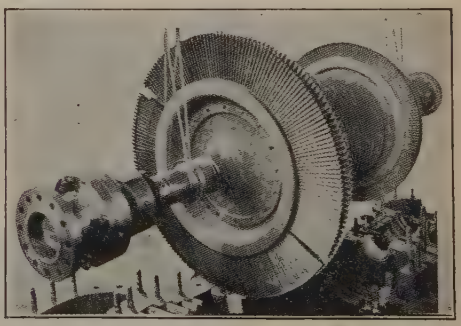


145. Model of a steam turbine.

The steam engine is used to move so many important machines that we could fill several books with their names and descriptions. Here are a few of them:

Water pumps are often operated with steam engines. So are the compressors which force illuminating gas into storage tanks. The power which drives many factories comes from the steam engine. Looms, printing presses, lathes, pressers and rollers are frequently dependent upon this type of engine. Tractors, drills, shovels and dredges are among the important movable machines which are steam-driven. Even the generating of electrical energy requires a steam engine in order to turn the dynamo.

Perhaps the most outstanding use of the steam engine is in the field of transportation. The steamship and the locomotive are to-day the chief means of long-distance travel.

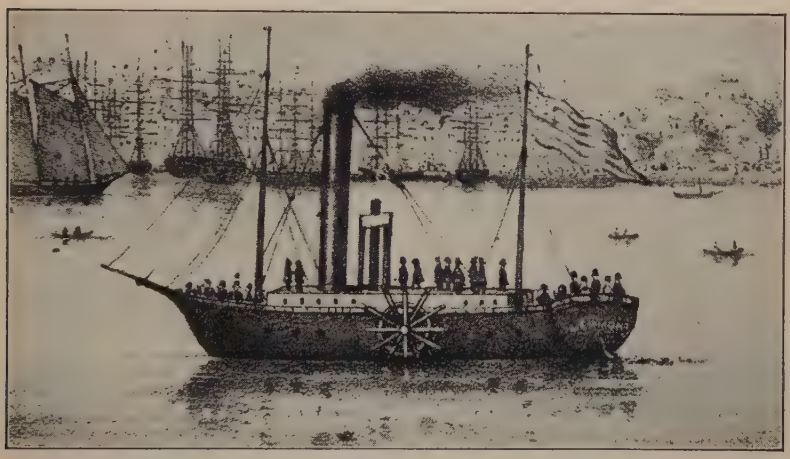


146. The moving part of a real steam turbine.

THE STEAMSHIP

The cheapest way to move freight and passengers from one point to another has always been by boat, but until the invention of the steam engine the only means of moving a boat was the oar or the wind. The newly invented engine suggested an improvement over hand power and wind power.

One man devised something like a duck's foot which the engine pushed through the water. Another used the engine to pump water into the boat at one opening and to pump it out again so forcefully through an opening at the rear that the boat would move forward. But these methods failed. In 1730, John Fitch invented his famous *Penny Packet*, which was propelled by paddle wheels turned by a steam engine. Though this was the first successful steamship,



147. Fulton's *Clermont.*

it was too slow moving to be practical. Rumsey and Stevens tried hard to improve on Fitch's efforts, but 75 years passed without much progress.

Finally, came Robert Fulton—an artist, who gave up art for invention. For some time he had been dreaming of a steam-propelled boat. Using the paddle-wheel idea, he built a small steamboat which he demonstrated to the great Napoleon. The emperor was so impressed that he exclaimed, "It is capable of changing the face of the world."

Fulton was encouraged to continue his experiments. He returned to America and built the famous *Clermont.* When it was finished, people laughed at it. They hailed it as "Fulton's Folly," but gathered in great crowds to witness the start of the first trip. On August 17, 1807, the boat cast off from her dock in New York

City. After one mishap which raised a great cry of disappointment and ridicule, the boat steamed up the Hudson River toward Albany, where it arrived 32 hours later. It also made a successful return trip. Fulton was proud of his achievement but somewhat bitter at the people who still doubted that it could be done again.

Of course, his boat was awkward and clumsy. The engine was exposed to view, the boiler was set in crude masonry, the machinery creaked, the paddle wheels splashed water and from the fire-box a stream of sparks went shooting into the sky. But it would run. The idea was sound. When Fulton died, eight years later, he had lived long enough to see the beginning of Napoleon's prophecy concerning his invention.

In 1819, the *Savannah* crossed the Atlantic Ocean in 27 days, during which time the ship had moved by steam power alone for 80 hours. In 1858 was built the first iron steamship for ocean travel. At about this time the side paddle wheels were given up in favor of a single-screw propeller. In 1889, the *City of Paris* adopted the twin-screw propellers, which method is employed to this day.

The next great improvement came in 1905, when the *Carmania* adopted the steam turbine instead of the steam engine (see page 175). To-day we have ships like the *Leviathan*, which is nearly 1,000 feet long, weighs 60,000 tons, can carry 5,500 passengers and crew and can cross the Atlantic in about four days. The modern steamship has become a floating palace, practically safe from wind, wave and storm, and is utilized by thousands of people each month to carry them to all parts of the world.

THE LOCOMOTIVE

Hardly had James Watt perfected the stationary steam engine, when men everywhere realized that it could be used to drive a wagon. Richard Trevithick, in England, was the first to build a road locomotive in 1804. It was a small machine, but it could haul 20 tons of ore. Later, he constructed a small circular passenger railway for the amusement of rich people.

There were other men, too, who experimented with locomotives. Blenkinsop and Hedley were among the more important

of these inventors. Their efforts were a stimulus to George Stephenson, who goes down in history as the father of the locomotive.

When he was eight years old, George went to work. No school for him—he would rather tinker with engines and dream about machines which could drag trains loaded with coal and passengers. Later he discovered that knowledge about engines could be had from books; and so at the age of eighteen he learned to read and write. Before he was 25, he was considered to be England's greatest steam engineer.

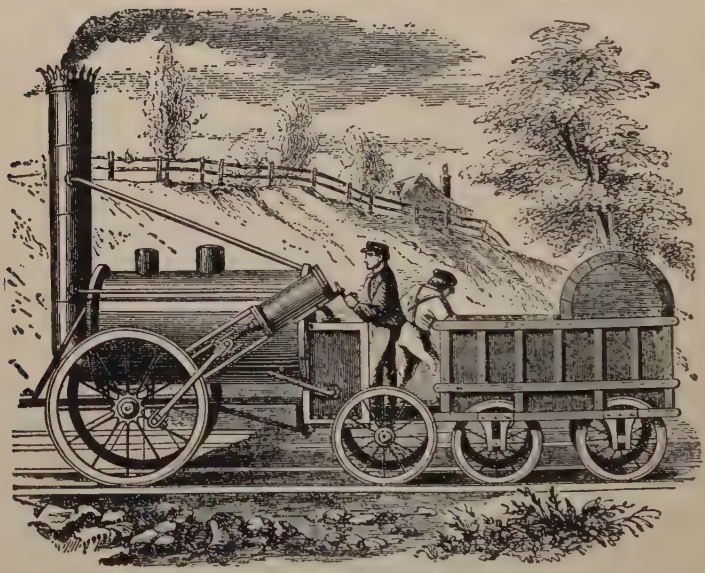
In 1825 a railroad was being planned and Stephenson was called in to superintend the work. When the road was opened, he built and drove the first locomotive, dragging a load of 90 tons. It is said that his locomotive was preceded by a man on horseback, who shooed off any cows or careless farmers that happened to be on the tracks. It seems that the horse had to gallop furiously at times to keep up with the train which was " flying " at the rate of 15 miles an hour.

When it was proposed to extend the railroad to other parts of the country, the government refused for a long time. It is laughable to read of the arguments used against the locomotive by the most intelligent men and the newspapers of that day. It was said by them that cows would not graze nor hens lay eggs when trains roared by; the air would be poisoned, birds killed, houses set on fire, and horses frightened to death. They declared that the boilers would burst, killing the passengers. " Furthermore," said they, " locomotives could never be a success; their weight would keep them from moving! " But truth triumphs eventually, and the government finally authorized the building of railroads.

One of the most interesting events in railroad history occurred at about this time. So many different styles of engines had been built that the directors of one of the railroads offered a prize of $2,500, to the maker of a locomotive which could travel most quickly a distance of 70 miles, hauling a load three times as heavy as itself. Refuelling would be permitted but once during the trip. Ten men entered the contest, but only four were able to get their locomotives ready in time for the trials, which took place at a place called Rainhill on Oct. 6, 1829.

People regarded the event as they would a horse race. Grandstands were built along the road, bands played and farmers from the surrounding country jammed the roads to Rainhill, anxious to see the spectacle.

The actual trials were not at all like a race, for each of the four locomotives was timed separately. Robert Stephenson, the son of George Stephenson, was in charge of one of the entries in the



148. The *Rocket* — Stephenson's engine.

contest. Father and son had built the famous *Rocket.* Their locomotive was ugly looking but business-like, for into its construction had gone all the experience that the Stephensons had gained with steam engines and with locomotives. For eight days, the *Rocket* plied back and forth along the road, hauling forty people up-hill and down-hill at a speed of 20 miles an hour. Some of their competitors had better-looking engines, some of them went faster; but all of them weakened or broke down before the test was over. The Stephensons were awarded the prize.

The famous *Rocket* still stands in a British museum as the forerunner of the modern locomotive. Though the engines have

changed in shape, grown larger in size and become more powerful in pulling strength, the railroad of to-day is still dependent upon the ideas developed in the *Rocket*. Every civilized country in the world is covered with a network of rails on which Watt's steam engine, driving Stephenson's invention, carries millions of people each day from one part of the earth to another.

HOW MUCH DO I REMEMBER?

A

What name in List X is connected with each of the following? Write your answers on a sheet of paper so as not to mar the book.

1. The invention of the air pump.
2. The invention of the gunpowder engine.
3. The effect of the gunpowder produced by the condensation of steam.
4. The introduction of the boiler into the steam engine.
5. The invention of a steam engine which was operated by the pressure of hot steam.
6. The first paddle-wheel steamship which was too slow to be successful.
7. The first really successful steamship.
8. The *Clermont*.
9. The first steamship to cross the Atlantic.
10. Adoption of the twin-screw propeller for driving steamships.
11. The adoption of the steam turbine for steamships.
12. The first road locomotive.
13. The Rocket.
14. The father of the locomotive.

List X

A. The City of Paris	E. Von Guericke	I. Papin
B. Newcomen	F. The *Carmania*	J. The *Savannah*
C. Fitch	G. Huyghens	K. Watt
D. Stephenson	H. Trevithick	L. Fulton

B

Among the statements below, select those which are false. You can make each of them true by changing one of the italicized expressions. Write the corrected statements on a sheet of paper.

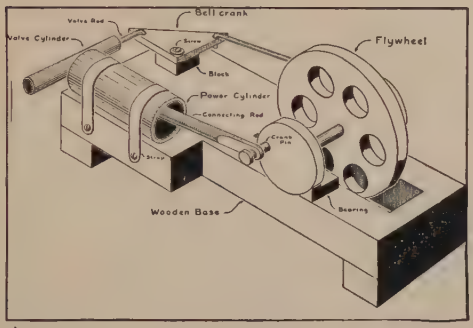
1. The invention of the steam engine was the work of *one man*.
2. The steam engine came into use *before* we learned to use simple machines.
3. A piston was first used in the *air pump* invented by *Von Guericke*.

4. In the gunpowder engine, the piston moved into *a vacuum* created by *the condensation of steam.*
5. *Watt* had great difficulty in making his engine because *it was hard* to *fashion his materials.*
6. Steam pressure is sometimes as high as *200 lbs. per square inch.*
7. There *is a limit* to the pressures which boilers can withstand.
8. If the pressure in a boiler is too great, *the steam-gauge* automatically opens and lets the excess steam out.
9. In the steam turbine, the pressure of the steam is used to *push a piston.*
10. Steam pushes the piston back and forth by acting first on one side of it *and then on the other.*
11. This action depends on *the slide-valve.*
12. Steam enters from the boiler into the *slide-valve.*
13. A steam turbine *is equipped* with a slide-valve.
14. The exhaust steam leaves the cylinder *always through the same outlet.*
15. The piston always moves *in the same direction* as does the slide-valve.
16. The *inertia* of the *flywheel* keeps piston and *slide-valve* moving steadily and smoothly.
17. The two spinning balls on the steam engine are part of the *governor.*
18. The *governor* keeps the engine running at a constant speed.
19. The steam turbine resembles a turbine *water wheel.*
20. The steam turbine is *an antiquated* style of steam engine.
21. Two prime movers of the Machine Age are the *lever* and the *steam engine.*
22. *The steamships and locomotives* are two of *the few* things moved by steam engines.
23. The locomotive *is the only* movable machine that depends on the steam engine.
24. Most large steamships to-day are run by *steam turbines* which turn *paddle wheels.*

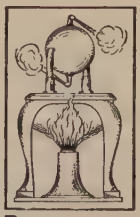
THINGS TO THINK ABOUT AND READ ABOUT

The steam engine is put to its most important uses in the locomotive and in the steamship. We are sure that you will want to read more about these uses. The following titles speak for themselves.

1. Building the Iron Horse.
   Book P, pages 829–847.
2. Mountain and Aerial Railroads.
   Book P, pages 2239–2254.
3. Ocean to Ocean Railways.
   Book P, pages 1113–1132.
4. Trade and the Road.
   Book P, pages 2529–2537.
5. The Locomotive.
   Book O, pages 2043–2044.

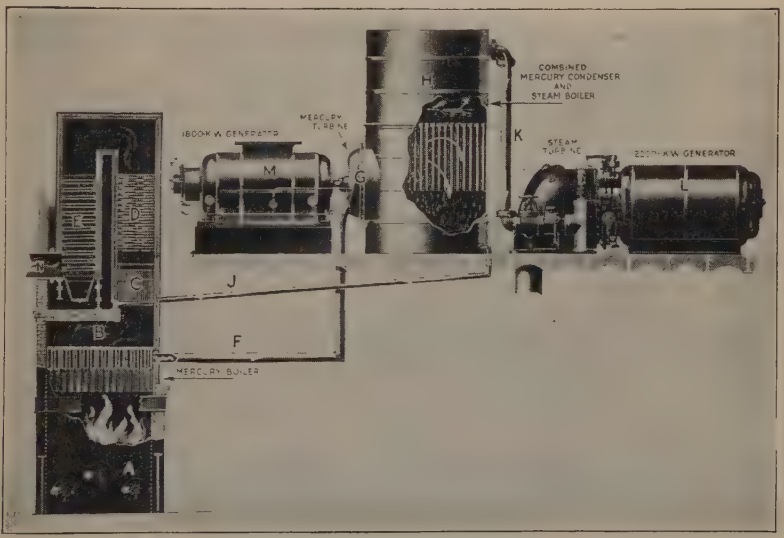


A



B

C



D

A. Make this steam engine model in the shop.

B. This is said to be the first steam engine ever made. Who made it? How does it work? C. What kind of engine is this?

D. In this engine mercury is used instead of water. What are the advantages of using mercury steam? Any disadvantages?

6. The Steel Roads That Commerce Travels.
   Book O, pages 2962–2972.
7. The Building of a Ship.
   Book P, pages 2393–2406.
8. Oars, Sails, and Steam—The Conquest of the Sea.
   Book O, pages 3207–3220.

The following references tell of the steam engine in general:

9. The Power of Steam.
   Book P, pages 1371–1381.
10. A New Era in the Steam World—Turbines.
    Book P, pages 387–396.
11. The Machine That Puts Steam to Work.
    Book O, pages 3348–3352.
12. James Watt.
    Book O, pages 3704–3705.
13. You will find the following articles in "A Popular History of American Invention," published by Scribner's:
    Putting Steam to Work—Volume 1, pages 467–503.
    From Stephenson to the Twentieth Century Limited—Volume 1, pages 3–67.

THINGS TO DO AND MAKE

1. Experiments with the changing of heat energy into work.
   Book D, pages 101–108.
2. Making model boilers.
   Book G, pages 195–223.
3. How to build a paddle-wheel boat.
   Book H, pages 105–107.
4. How to make a model steam engine.
   Book D, pages 48–51; Book E, pages 247–255.
5. Making a horizontal slide-valve engine.
   Book G, pages 136–164.
6. Making a model steam turbine.
   Book G, pages 165–186; Book E, pages 238–247; Book H, page 180.
7. Steam tops.
   Book G, pages 187–194.
8. Making a Barker's mill with steam.
   Book C, pages 259–261.

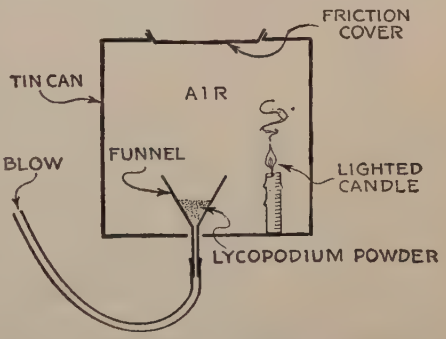
CHAPTER XIII

THE GASOLINE ENGINE

DEAR BOB:

This is the long letter which I have often promised to write you. In fact, I have so much to say that your patience may be sorely tried before you finish reading. However, any one who professes to be a scientist, as you do, should make a good audience, for I am about to relate the most interesting set of experiments I have ever seen.

As you know, I am a member of the Newton Science Club. We meet each week to discuss the latest discoveries in the world of science and to watch demonstrations by various members. Every now and then our club sponsor, Mr. Rowen, asks permission to give a number on the program and he always has something worthwhile to offer.

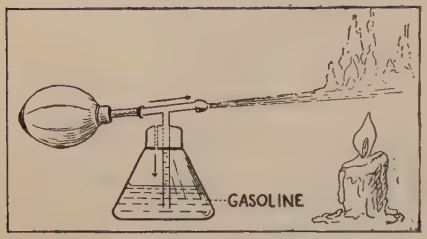


150. How Mr. Rowen exploded the tin can.

Last Wednesday's meeting was such an occasion. Mr. Rowen greeted us with a table full of apparatus and after the usual brief business was over, he began his lecture. I wish you could have been with us. With your interest in experiments you would have seen enough to keep you busy for a year.

First, Mr. Rowen announced that his subject was the *Gas Engine*—the engine that runs by explosions. "Explosions are terrible things," he said, "when they are not controlled. But man's business is to control them so that they do useful work." While talking, he lighted a small candle, which he lowered into a tin can. I noticed that the can had a hole in its bottom. Then he poured some powder into a glass funnel and this also he lowered into the can, with the stem passing through the hole. The powder, he explained, was called *lycopodium* and could be bought in the drug store. To the stem of the funnel he attached a long rubber tube and then he called upon me to take the end of the tube in my mouth. Finally, he clamped the cover on the can, moved away from the table and shouted, "Blow!" Innocently, I obeyed. A second later, there was a crash. The cover of the can flew off and hit the ceiling. I was too stunned to mind the laughter, though I wasn't hurt at all.

I have made a drawing of this experiment (see figure 150), so that you can repeat it, if you wish. As I understand it, lycopodium powder is ground very fine. When you blow into the funnel, the particles are scattered and thoroughly mixed with the air in the can. The candle flame ignites the mixture and the latter burns rapidly and completely. There isn't room enough in the can for the gases given off during the rapid burning and so the cover pops off with a bang.

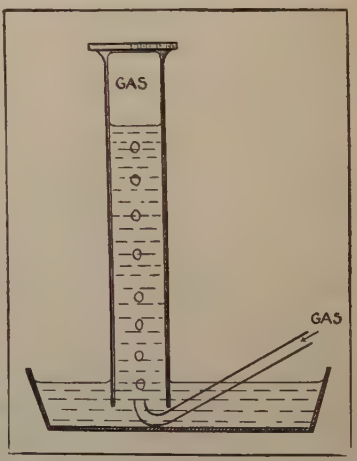


151. Vaporized liquid fuel burns readily.

Mr. Rowen then went on to say that very small particles of any burnable substance can produce the same result. He lighted a match and quickly thrust the burning end into a small dish of kerosene. To our surprise the match went out and the kerosene did not burn. The explanation is, that kerosene liquid must first be broken up into small particles and mixed with air before it will burn.

Pouring the kerosene into an atomizer bottle, Mr. Rowen squeezed the bulb so as to send a stream of kerosene particles through the air and over a lighted candle. Long tongues of flame leaped up from the candle at every squeeze. The effect was very striking. (See figure 151.)

"Now," said Mr. Rowen, "let us use a fuel which is already broken up into very fine particles. You do not have to blow it by mouth or with an atomizer. Furthermore, it is not a solid fuel, like lycopodium powder, or a liquid fuel, like kerosene. It is a gaseous fuel—ordinary illuminating gas."



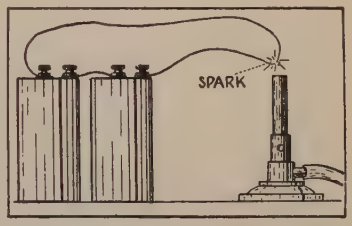
152. How to collect an amount of illuminating gas.

He next attached a rubber tube to the gas jet and placed the end of the tube in a jar of water. As he turned on the gas, it bubbled up to the surface. He filled a tall glass cylinder with water and inverted it so that its open end was under water, and above the stream of rising bubbles. As the gas rose in the cylinder, the water was pushed out and soon the cylinder was filled with gas. See figure 152. He removed the cylinder, covered the open end with a piece of cardboard and righted it on the table.

When he brought a lighted match to the gas collected in this way, we all expected another explosion; but again we were surprised to see the gas burning quietly at the mouth of the cylinder, where there was air to support combustion.

Noticing that many of us were disappointed at the lack of an explosion, Mr. Rowen asked us to offer suggestions as to how to explode the illuminating gas collected in a cylinder. Fred Johnson's idea was the one accepted, and this is how it is was done:

Instead of permitting the gas to push out all the water in the glass cylinder, only ¼ of the water was displaced. The gas was shut off, the cylinder removed and the remaining water spilled. In emptying the cylinder, the space occupied by water was immediately filled by air, so that the cylinder now contained a mixture of ¾ air and ¼ gas. Fred was then asked to bring a lighted match to the mixture. As he did so, a loud shot rang out. The explosion was a success.

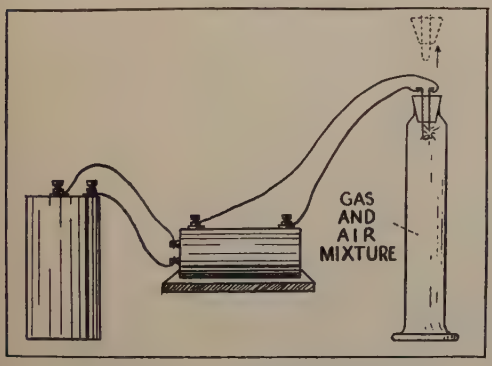


153. Igniting a fuel with an electric spark.

This gave me an idea; for it seemed to me that the force of the explosion could be used to shoot a bullet. Mr. Rowen was rather pleased with my suggestion, for immediately he said:

"Very well, boys, let's shoot a bullet. First we shall fill the cylinder with an explosive mixture, then we shall cork it up. If we can only ignite the mixture, won't the cork travel!"

He put it up to me to set off the gas, but how was I to bring a lighted match to something which was completely corked up in a glass cylinder? I was stumped. Then other boys got busy thinking. All sorts of wild schemes were proposed until Mr. Rowen, who was listening silently, picked up two wires and connected them to an induction coil. A spark jumped across the air gap of the coil. We didn't see the significance of this, until he pulled over a bunsen burner and lit it with the electric spark. Then we realized that he was hinting at the solution. A dozen of us saw the point at once. Johnny jumped up to say that we could stick two wires through the cork and produce a spark across the ends inside of the cylinder.

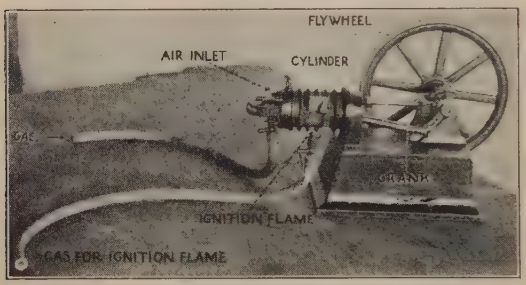


154. Exploding a mixture of gas and air.

This was soon done. (See figure 154.) When everything was ready, Mr. Rowen tilted the cylinder at an angle so that it was aimed at an open window. It looked like a cannon about to be fired. "Ready, aim, fire!" called Mr.

Rowen, as Johnny made contact at the battery. Pop! The cork flew out of the window and landed on the roof of a house across the street.

After repeating this experiment several times, Mr. Rowen brought out a small engine about the size of his fist. It was a toy gas engine. It had a cylinder into which illuminating gas could be fed from the gas jet. The latter was connected to a flywheel, which was turned as the piston moved back and forth. In the side of the cylinder was a tiny hole and near it was a lighted gas jet to ignite the mixture in the cylinder. With his hand, Mr. Rowen spun the flywheel around a few times. We soon heard the sound of exploding gas as the little engine began popping along like a motor-cycle.



155. Parts of a toy gas engine.

It was most interesting to see this tiny engine work. Each exploding charge of gas and air made the flywheel whiz around. We were able to connect a rubber-band belt from the pulley of the flywheel to the pulley of a small dynamo. The dynamo spun round so fast that it generated enough electricity to light a flashlight bulb. At last, we saw what Mr. Rowen meant when he said that the gas engine is an engine which is run by explosions—explosions that are controlled by man so that they do useful work.

I have finished my story; and though it has taken me a long time to tell it, I hope you have not been bored. When I visit you next summer, I expect to get your help in doing over again as many as possible of these experiments.

With kindest regards and best wishes, I am

Your friend,

JACK

1. Gasoline vaporizes rapidly at normal temperatures

When Huyghens invented his "gunpowder" engine in 1690, he gave the world an idea which resulted in two inventions. The first was Watt's steam engine. See page 168. The second was Le Bon's gas engine, which was first demonstrated in 1799. Le Bon realized that the force of an explosion which Huyghens used to produce a vacuum inside of a cylinder might rather be used to push a piston. His engine is the ancestor of all modern gas engines.

But Le Bon and his followers used illuminating gas as their explosive fuel. This required huge storage tanks and made

almost impossible the use of the engine in a vehicle. It was not until 1850, that Doctor Kier discovered a wonderful liquid fuel. He found that when petroleum is heated, the lighter parts are boiled off, and that these may be condensed again into several different liquid fuels. The very lightest, gasoline, he allowed to escape because it was too dangerous, too explosive. He retained the kerosene. To-day we can hardly obtain enough of this " dangerous " fuel to run the millions of automobiles in the world.

You can observe how readily gasoline evaporates by dipping a sponge into some gasoline and wiping a streak with it on the blackboard. Do the same with another sponge moistened with water. Which evaporates more quickly? The more rapidly gasoline evaporates, the better is its quality.

156. Cross-section view of a spark-plug.

Doctor Otto in Germany was among the first to use gasoline in an engine similar to the one devised by Le Bon. This was in 1876. He found that gasoline changed so readily into a vapor that it could be substituted for illuminating gas. Furthermore, liquid gasoline was light and could be stored in a small tank. The Otto engine made the automobile possible, not only by its use of a light liquid fuel, but through several other devices which are described in this chapter. He showed how the gasoline liquid may flow or be forced from the storage tank to a vaporizer into a chamber where it is mixed with air, and into a cylinder where an electric spark ignites the explosive mixture.[1] The action of piston, flywheel and valves was also developed in Otto's engine.

2. A suitable mixture of gasoline vapor and air may be readily exploded

Fuels do not burn at all if no oxygen is present. They burn slowly if some oxygen is present. But if the right amount of oxygen is mixed with a gaseous fuel, the burning takes place so rapidly that we call it an explosion. Of course, the mixture must be raised to its kindling temperature before the explosion occurs.

[1] The vaporizer and mixing chamber are included in the device known as the *carburetor*. This device is more fully explained in the next chapter, page 202.

Examine carefully the following comparison between burning and exploding:

Conditions Necessary for Burning	Conditions Necessary for Exploding
1. The substance must be burnable.	1. The fuel must be divided into very small particles (vaporized).
2. Oxygen must be present.	2. The right amount of oxygen must be present.
3. The substance must be raised to its kindling temperature.	3. The mixture must be raised to its kindling temperature.

In a gasoline engine the fuel is vaporized by a device known as a carburetor. (Condition No. 1.) In a chamber of this device the particles of gasoline vapor are mixed with the right amount of air. (Condition No. 2.) Usually, a mixture of 16 parts of air to one part of vapor results in the most forceful explosion. The third condition, that having to do with kindling temperature, is met by means of a spark plug. The spark plug is like the wired cork described on page 187. It brings the ends of two wires near each other inside the cylinder. An induction coil is connected to these wires so that a hot electric spark flashes across the gap between their ends. The spark ignites the explosive mixture.

3. The explosive mixture is drawn into the cylinder (Intake stroke)

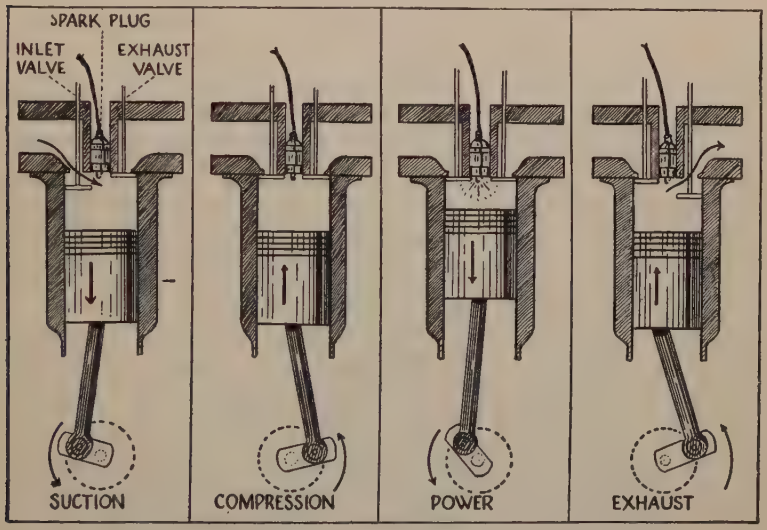
In figure 155 are shown the parts of a simple gasoline engine. Examine the picture carefully so as to become familiar with such parts as the cylinder, the piston, the spark plug (see figure 156), the inlet and exhaust valves, and the flywheel.

To start the engine, an electric switch is closed so that the induction coil can operate to supply an electric spark at the spark plug. Then the flywheel is turned or cranked rapidly. As the flywheel turns the piston is moved. When the piston moves down quickly, it acts like the piston in a pump, creating a partial vacuum in the cylinder. The pressure of the air outside forces open the

inlet valve, and the explosive mixture flows into the cylinder. See figure 157.

4. The explosive mixture is compressed by the piston (Compression stroke)

Since the flywheel has been given a sharp turn, its inertia keeps it turning. Hence, the piston begins a return trip through the cylinder (upward) after the first stroke is completed. Since both



157. The four strokes in each cylinder of a gas engine.

valves are kept shut during the return trip, there is no place for the explosive mixture to go. The mixture is therefore compressed. Also, it gets hot because of the compression. In fact, it is quite ready to be exploded.

5. An electric spark ignites the mixture and the resulting explosion drives the piston (Power stroke)

Just when the explosive mixture is under greatest compression a certain lever causes an electric spark to jump across the gap of the spark plug, inside the cylinder. The gasoline burns rapidly

in the air with which it is mixed (it explodes), and a great many gases result from the burning. There is so much gas, in fact, that the cylinder is crowded with it. The burnt gas exerts great pressure in the inside of the cylinder, and moves the piston down again quite violently. This powerful stroke of the piston keeps the flywheel turning. If the flywheel pulley happens to be belted to some machine, the machine will also be turned by the force of the piston.

6. The burnt gases are pushed out of the cylinder (Exhaust stroke)

The cylinder is now full of burnt gases. If there is to be another explosion, these gases must be gotten rid of. This is accomplished in the following manner:

After the piston has been kicked by the explosion as far as it will go, it must return. As it begins its trip upward through the cylinder, a certain lever causes the exhaust valve to open. The burnt gases escape through this opening.

7. As the engine continues to operate, the four strokes described above are repeated in order

In parts 3, 4, 5 and 6 above we have described four strokes of the piston in the cylinder. When the *exhaust* stroke (explained in part 6) is completed, another intake stroke is begun. This is followed by a compression stroke, which in turn is followed by a power stroke. The sequence of events is therefore: Intake, Compression, Power, Exhaust—and so on.

Because of the 4 strokes in a gasoline engine of this type, it is often referred to as a *four-cycle* engine. There are also two-cycle engines, most frequently used for motor-cycles, motor-boats and outboard motors for rowboats.

It is interesting to note that after the first cranking of the flywheel by hand, the energy for all four strokes is obtained from the power stroke. Of course, in large gasoline engines, the initial cranking is rarely done by hand. An electric starting motor is provided for that purpose, but sometimes the motor or the battery

gets out of order; and then one must crank by hand to start the engine. Motor-cycle engines are usually cranked by foot power and outboard motors for rowboats by hand power.

A very important problem in all gasoline engines, and the source of many engine troubles is improper timing of spark and valve. If you study what happens during each of the four strokes of the piston, you find that the intake valve must open but once in four strokes; namely, at the beginning of the intake stroke. The spark plug must spark exactly at the end of the compression stroke; and the exhaust valve must open at the beginning of the exhaust stroke. There is no need, in this book, to explain just how this is accomplished; but we urge you to watch closely whenever you see a gasoline engine in action. If such an opportunity arises, ask someone to point out the *timing gears*, and the cam rod; for it is these parts that accomplish correct timing.

8. A gasoline engine operates more smoothly when the number of cylinders is increased

For every four strokes of the piston, there is one explosion. This explosion furnishes the power. Hence the flywheel and the shaft on which it turns receive a sudden jolt at regular intervals. This does not make for smooth operation, even though the inertia of the heavy flywheel tends to smooth out the sudden jerks. The most effective way to get smooth operation is to mount several cylinders, so that the several pistons apply their force to the same flywheel, but not at the same time. In an engine of four cylinders, the explosion would occur first in Cylinder No. 1, then in No. 4, then in No. 3, and finally in No. 2. Thus, the flywheel receives two jolts in every revolution instead of one jolt in every two revolutions, as would be the case in a one-cylinder engine. By applying the power more evenly, the engine runs more smoothly.

Six-cylinder and eight-cylinder engines are quite common in automobiles. The greater the number of cylinders, the greater is the number of pistons, valves, spark plugs, cams, gears and other parts. Also, the greater is the possibility of something going wrong. However, we are willing to put up with frequent repairs and increased expense, for the sake of riding more smoothly.

HOW MUCH DO I REMEMBER?

A

Pick out the correct completion (see list) for each of the following. Write your answers on a sheet of paper so as not to mar the book.

1. Mr. Rowen's experiment with lycopodium powder proved that
2. His experiments with kerosene proved that
3. His experiments with illuminating gas proved that
4. His experiment with shooting a bullet proved that

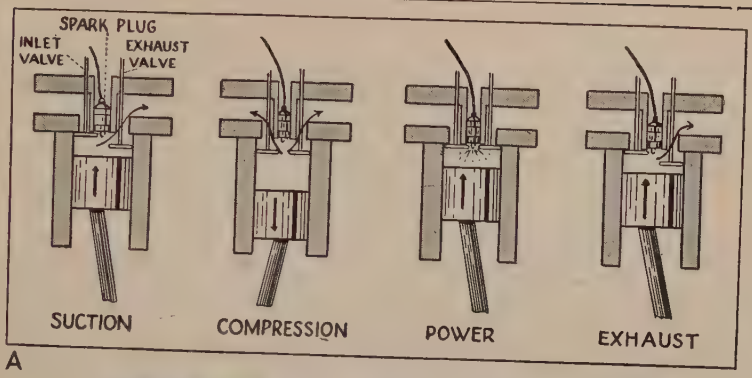
Completions

A. fuel must be mixed with the right amount of oxygen before it can explode.
B. a fuel can explode only if it is divided into very small particles.
C. a spark can ignite an explosive mixture that is inclosed in a cylinder.

B

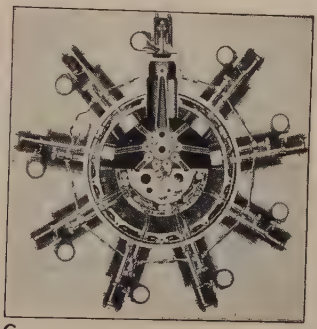
Select the word or words which will make each of the following a correct statement:

1. The first to use an explosion in running an engine was (LeBon, Huyghens, von Guericke).
2. In the "gunpowder" engine the explosion (pushed the piston, created a vacuum).
3. In Le Bon's gas engine, the explosion of (gasoline, illuminating gas, gunpowder) (pushed the piston, created a vacuum).
4. In the Otto engine, the explosion of (gasoline, illuminating gas, gunpowder) (pushed the piston, created a vacuum).
5. Gasoline displaced illuminating gas in the engine because (it could be stored more easily, it was cheaper, it did not have to be vaporized).
6. Gasoline is distilled from (coal, kerosene, petroleum).
7. In an explosion, fuel burns (very slowly, very rapidly).
8. In a gasoline engine, the fuel is vaporized by the (spark plug, induction coil, carburetor).
9. The most forceful explosion usually results from a mixture of (3 parts of oxygen to one of gasoline vapor, 16 parts of oxygen to one of vapor, 16 parts of vapor to one of oxygen).
10. The spark plug supplies the (kindling temperature, air mixture, fuel vaporization) for the explosion.
11. The inlet valve is connected to the (induction coil, carburetor, exhaust).
12. After the switch which controls the induction coil is closed, the engine (starts immediately, can be started by turning the flywheel).
13. After the explosion there is (more gas than there was before, less gas, an equal amount) in the cylinder.
14. If the spark plug does not spark at exactly the correct moment, there is something wrong with the (induction coil, timing gear and cam shaft, carburetor).
15. An engine can run more smoothly (if it has 4 cylinders, if it has 12 cylinders, regardless of the number of cylinders).

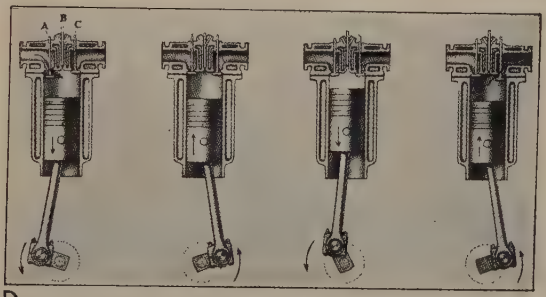


A

B



C



D

A. What's wrong with this picture?
B. Where is this type of gas engine employed?
C. Where is this type of gas engine employed?
D. This shows the strokes in a Diesel Engine. How does the Diesel Engine differ from the gas engine? What are its advantages over the gas engine? Any disadvantages?

16. An engine with 2 cylinders (is, is not, may be) more powerful than one with 4.
17. In an eight-cylinder engine, each piston turns (the same, a different) flywheel.
18. In a four-cylinder engine, the power stroke of each cylinder takes place at (the same, a different) time.
19. (All, some, no) gasoline engines are two-cycle engines.
20. In large engines, the initial cranking is usually done (by hand, by electric motor, by nothing since it is not necessary).

C

On a sheet of paper make four columns with the following headings:

Intake Stroke *Compression Stroke* *Power Stroke* *Exhaust Stroke*

As you read each of the statements below, decide upon the column or columns to which it refers. Then place its number in the proper column or columns. If a statement seems to have no relation to any column, do not list it at all.

1. Follows the intake stroke.
2. Follows the exhaust stroke.
3. Follows the compression stroke.
4. Follows the power stroke.
5. The piston moves away from the spark plug.
6. The piston moves toward the spark plug.
7. The inlet valve is open.
8. The exhaust valve is open.
9. Both valves are open.
10. Both valves are closed.
11. The explosive mixture flows into the cylinder.
12. Inertia keeps the flywheel moving.
13. A force is applied to the flywheel.
14. Ignition takes place.
15. Burnt gases are pushed out of the cylinder.
16. The spark plug sparks.
17. The energy for all four strokes is supplied.

THINGS TO THINK ABOUT AND READ ABOUT

1. Engines in which the fuel is burned inside of the cylinder are called internal combustion engines. The gasoline engine is of this type but the steam engine is not. A type of internal combustion engine which is rapidly coming into prominence is the Diesel engine, invented by Rudolph Diesel in 1893. The fuel in a Diesel engine is heavy, non-explosive oil. Unlike the gasoline engine it has no spark plug. Air is admitted into the cylinder and is so strongly compressed that it gets extremely hot. Into the hot air, oil is sprayed and the resulting explosion pushes out the piston. The Diesel engine is being made very

efficient and is employed wherever light, powerful engines are required. Find out about Diesel engines in

Book O, pages 1406, 3375–3376; Book P, pages 1422–1423, 1609–1624; Book K, pages 12, 252.

2. The story of how the motor-cycle was invented is a very interesting one. The first man to use an engine to push around the pedals, attached a small coal-burning steam engine to the bicycle. It is too bad that there is not to-day a motion picture with sound effects of this contraption. Read about it in

   Book O, pages 274, 391; Book P, pages 4279, 4287; Book K, pages 52–58.

3. When Drake struck oil in 1859, kerosene was the fuel used in lamps and stoves throughout our country. It was kerosene which the first oil wells supplied. The large amounts of gasoline contained in crude oil were almost useless and many states had to pass laws against the dumping of gasoline into rivers. At present, the two million barrels of gasoline produced daily are barely enough. Engineers are trying to get from crude petroleum every bit of gasoline that it contains. They are constantly trying to find substitutes for gasoline. Perhaps the future will see alcohol take its place as the fuel for automobiles, for alcohol can be produced cheaply from waste woods, stems, etc., whereas the world's supply of gasoline is rapidly becoming exhausted.

   When gasoline is separated from crude petroleum, a certain amount of kerosene is mixed with it. This prevents proper burning in the cylinder and causes "knocking" while the engine is working. To eliminate this, certain chemicals are mixed with the gasoline. One of the most effective antiknock chemicals is tetra ethyl lead. Gasoline treated with this chemical is called ethyl gasoline. You will find many more facts about gasoline in an article called "Better Fuels for Better Motors" in Popular Science Monthly for February, 1930. Read also Book O, 1014, 1408, 2753; Book P, pages 1612–1613, 4958.

4. The airplane engine must be light and powerful. If the gasoline engine had not been invented the airplane would perhaps be impossible. But the gasoline engine itself has been improved to suit airplane needs. A 100-horsepower engine used to weigh 5 tons. Nowadays, such an engine may weigh as little as 300 pounds. Read

   Book O, pages 56, 58, 60, 65; Book P, pages 534–535.

5. Motor-boat engines.

   Book O, pages 445, 2357; Book P, page 4279.

6. Engines in dirigibles.

   Book O, pages 314, 316, 318–319.

7. Some railroad trains are run by a combination of the gasoline engine and electric motor. The engine generates electricity which is sent to the other cars to run their motors. Read

   Book K, page 214.

8. You will find the story of various kinds of engines in "The Story of the Engine" by W. F. Decker. (Scribner's)

CHAPTER XIV

THE AUTOMOBILE

When Daimler built his motor-bicycle in 1885, he did not dream that forty years later his vehicle would result in the millions of automobiles which clutter up the modern city street. His gasoline engine on wheels has changed American life completely in less than half a century.

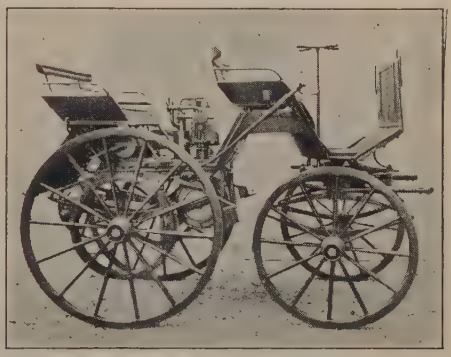
Let us trace some of the steps in the rapid rise of the automobile. Before Daimler's time, there were many inventors of vehicles that would go by themselves. Roger Bacon in 1275 speculated on the possibility, and in 1619 a patent was granted in England for "drawing carts without horses." Even Isaac Newton, who is famous as a scientist rather than as an inventor, once devised a steam car. When Watt invented the steam engine, there was a flood of steam-driven vehicles, but the development swung rapidly toward the locomotive, as we learned in Chapter XII.

It was Otto's gas engine, however (see page 189), which made the automobile a practical possibility; for the new engine was both light and powerful. Daimler was an engineer in the Otto Engine Works for ten years. At the age of 50 he resigned his position to open his own shop, where he could give all his time to the improvement of a vehicle driven by a gas engine. Men in other countries were working on the same problem. Levoir, in France, Markus in Vienna, and Gardner in England all produced fairly successful motor cars. But Daimler's products are considered by many to have been the most successful. His first effort was the motor bicycle, then he made a tricycle and finally a four-wheeled machine which he called the *Mercedes*, after his daughter. This car, in its modern form, is still being manufactured and is among the few best makes of automobiles. So far as we know, Daimler's car was the first to adopt the water-cooling system, the suction carburetor, the cone-clutch, the sliding transmission gear, and the V-type engine. In the invention of these devices he was assisted by the engineer,

Maybach, who must be given a prominent place in automobile history.

Since we are mentioning names, we should also add that of Benz in Germany who disputed Daimler's patent claims, that of Levassor in France, whose patents cover the arrangement of automobile parts almost as they appear in the modern car, and that of Selden in America whose patents were granted in 1879.

From this point on, the development of the automobile is almost too rapid to follow. Improvement followed improvement. The Haynes car, the Oldsmobile, the Ford and several others were first marketed at about the beginning of this century; each possessed some unique feature which made it popular. Our country is so rich in natural resources and our growth in population is so steady, that materials and workmen have always been readily available for turning out automobiles. We now lead the world in this industry; but until very recently, dozens of manufacturers could not supply the demand for automobiles.



159. Daimler's car.

When orders for cars first began to pile in, engineers realized that new methods of manufacture were necessary. They could no longer rely on fashioning parts by hand. Instead of casting one cylinder at a time, they learned to cast six of them in one block. One boring machine was used to bore all the cylinders in a single operation. Instead of drilling one bolt-hole at a time, a dozen or more were pierced through the metal at a stroke. Automatic machines were invented, that could quickly turn out thousands of duplicate parts. Any one gear or rod was so made that it could fit any car of the same make.

But the rapid duplication of parts brought with it another problem. How could the pieces be quickly assembled into a complete automobile? The practice had been (and still exists in many

European factories) for a skilled workman to fit all the needed parts together. This was slow work; while people simply clamored for cars and more cars.

Henry Ford was one of the first to solve this problem by developing what is known as " progressive assembling." The frame of an automobile starts moving through the factory, and as it passes a workman the latter fits one and only one part in place. A second workman is in charge of another part and so on. By beginning at one end of the factory and following the movement of the frame, one can watch the gradual accumulation, until a finished automobile rides out into the yard on its own power. When a Ford plant is working at full capacity, such a trip might last about half an hour. By this method, the automobile price became cheaper; thus creating more customers than before.

As the number of cars increased, good roads became necessary and they were built. Cities were brought closer together, and business was therefore stimulated. New industries sprang into existence and flourished. Ways of living changed because people could get about faster and go further. Automobiles for pleasure kept pace with automobiles for business. People could now visit with each other more often, because it took less time. They could live in the city and yet enjoy frequent visits to the country. Also, the farmer did not need to feel isolated, because a 30-minute ride could bring him to friends and to places of amusement.

The automobile has brought other changes in our ways of living, for it has practically done away with many trades, such as wagon-making and blacksmithing. However, it has created many new and profitable occupations, such as garage mechanic and automotive engineer. It has brought with it, also, an element of danger. Thousands of people are hurt or killed each year in automobile accidents. Traffic has become so congested, that the automobile becomes practically useless at times in certain places. Finally, it has given the criminal another tool with which to prey on mankind.

Like many of the gifts of science, the automobile can be used either for the welfare of man or for his destruction. Just as fire, the servant of man, may sometimes become his master, so the

automobile may be servant or master, depending upon how man uses it.

In the remainder of this book, we shall learn about the details of construction of a modern automobile, and how some of the important parts operate. One of the interesting facts to be noted is that you can find in the automobile an application of nearly every law and principle of science you have thus far studied.

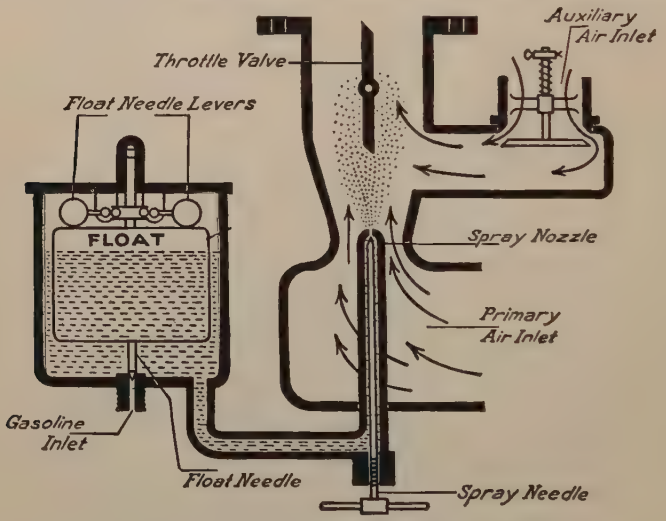
1. Air principles are applied in the automobile

One of the great difficulties with the early automobile was that the engine would suddenly stop. The driver would get out and examine his machine. Plenty of gas, plenty of oil, no broken parts, no loose wires and yet something was wrong. He would crank until his arms were tired, without result. In nine cases out of ten the trouble was with the *carburetor*, which was out of adjustment. Now, what is a carburetor?

160. Henry Ford and his first car.

In the preceding chapter, we learned that the rapid burning of gasoline vapor (the explosion) results in a pressure of burnt gases on the piston. All the power of the engine is derived from this pressure. But burning is impossible without air, and for rapid burning just the right amount of air is needed. The carburetor, which vaporizes the liquid fuel and mixes it properly with air, is a very sensitive device. It must accommodate itself to air of different temperatures, air at different altitudes, clean air and dusty air and it must prepare proper air mixtures at all speeds of the engine. Only in the last few years has the carburetor been perfected to the point where automobilists need not worry about it.

The modern carburetor is a complicated device, but most of its important features may be studied in figure 161. Liquid gasoline from the tank flows through the inlet, past the float needle. This needle is raised when the float drops, which happens when the float chamber is empty. But as the gasoline fills the chamber, the float rises and pushes the float needle-levers, and then they push down



161. Parts and operation of a carburetor.

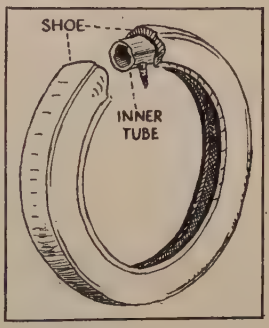
the needle so as to close the inlet. In this way the float chamber is always kept filled with liquid gasoline.

Now, let us give our attention to the rest of the carburetor, to the right. The liquid fuel flows down through the side pipe to the spray needle. If the throttle valve is open, as shown in the drawing, the suction of the pistons in the cylinders creates a partial vacuum around the spray nozzle. To fill this vacuum, air and gasoline vapor rush together toward the throttle. When the driver " steps " on the accelerator he causes the throttle to open wide, and as he does so, the explosive mixture flows into the cylinders.

That is all there would be necessary in a carburetor, if the engine could be run at a constant speed. However, the speed of an automobile must and does change constantly. When the pistons

move slowly, the partial vacuum created at the spray nozzle is not great, but when the pistons move fast, this vacuum is nearly perfect. Hence, more vapor is drawn in at high speeds; and this makes necessary more air, if the mixture is to be just right. The extra air needed at high speeds comes in through the auxiliary air inlet which is opened by the force of air pressure against the spring. The spring keeps it closed when the speed is slow.

From the above, it may be seen how dependent upon air an automobile is, and how important is the pressure of air in the operation of a carburetor. Yet, that is not the only part that air plays in the running of an automobile. In order to flow from tank to carburetor, gasoline is usually forced along by air pressure. The automobile itself can be said to ride on air, because the rubber tires are full of it.



162. The use of air in an automobile

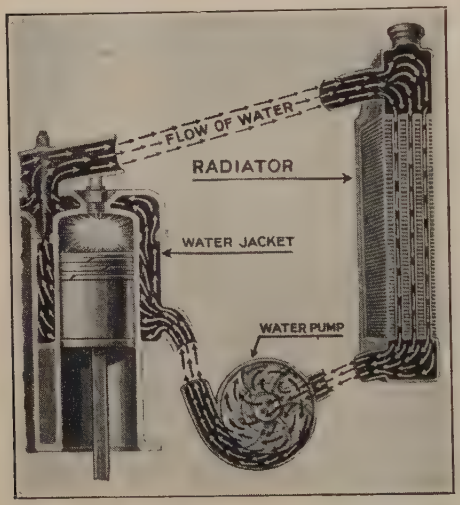
Every gas station is provided with an air pump and hose, by which are filled the deflated tires of automobiles that stop to purchase fuel. Also, air is used to cool the engine. The radiator is honeycombed so that it presents a large cooling surface to the air, and a fan behind the radiator keeps a current of air moving past the hot metal of the cylinders. Some engines are entirely air-cooled, as in the case of the motor-cycle and the airplane. The advantage of air cooling over water cooling (described in the next section) is that it makes the engine lighter. Every cubic foot of water weighs more than 60 pounds.

Finally, we must consider the effect of the air in streets and garages of the burnt gases which come from automobile exhausts. Carbon dioxide and carbon monoxide are shot into the atmosphere by every running automobile. Carbon monoxide, in particular, is very poisonous and has caused many deaths. Out in the open, the breeze soon dissipates the poison, but in a closed garage, the gas accumulates. One of the great problems in designing the Holland Tunnel was to find some way to get rid of the vast quantities of burnt gases coming from the exhausts of thousands of automobiles, as they ride through the tube. The successful solution of this

problem makes the Holland Tunnel one of the great wonders of the world.

2. Water principles are applied in the automobile

Whenever a motorist starts on a long trip he sees to it that the engine is in good condition, but one of the last things he does, when everything else is right, is to fill the radiator with *water*. Should he stop on the road for gasoline and oil, the garage man almost always looks into the radiator to see if it is filled. Water is as essential to the proper operation of the car as are gasoline and oil. Let us see why this is so.

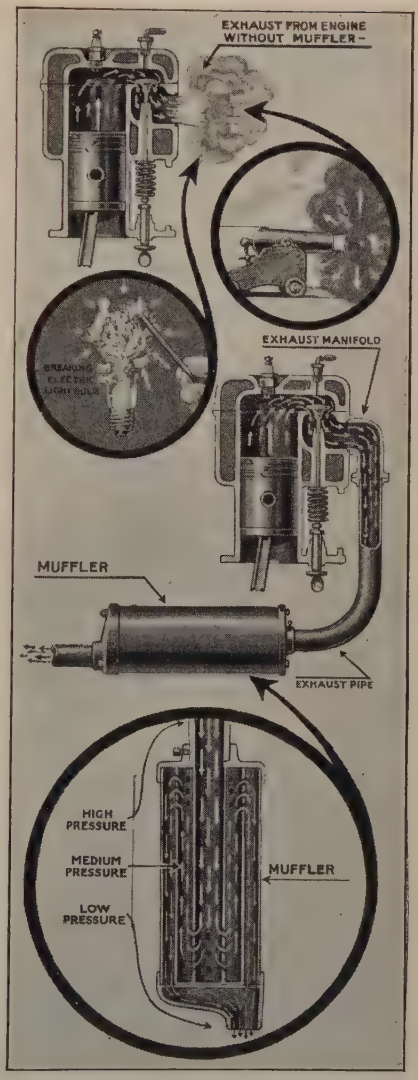


163. Cooling system in an automobile.

Every explosion is accompanied by heat. Hence, the metal cylinders and other parts of the engine become very hot. A certain amount of warmth keeps the engine running smoothly, but too much heat may crack the cylinder and do other serious damage. It is therefore necessary to cool the engine. Since water can absorb a great deal of heat, it is a good liquid to use in the cooling process. The cylinders are surrounded with a metal jacket which contains water. The warmed water rises, flows to the radiator, and there loses its heat to the air.

Figure 163 shows how the water circulates. As the water cools in the radiator, it drops to the bottom and flows into the jacket. The warm water in the jacket rises, as indicated by the arrows, and flows to the radiator. The pump helps to keep the water in circulation and is driven by the power of the engine itself. Note also that this is not the piston type of pump. The water is pushed along by rotary blades.

An automobile engine gets hot after running for a time, even in the coldest weather, so that a cooling system must be employed. However, there is always the danger of a frozen radiator when the engine is idle and exposed to low temperatures. When water freezes, it expands in volume, and since there is no extra space available either in the water-jacket or in the radiator, the metal walls may crack. Hundreds of autos are ruined each year in this way. In order to meet this danger, alcohol or glycerine is mixed with the water, for instead of freezing at 0°C, which is the usual freezing point of water, the mixture does not freeze until it is cooled to many degrees below zero. Such low freezing points are rarely reached. Recently, several "antifreeze mixtures" have been put on sale, which act exactly like alcohol and glycerine, in that they lower the freezing point of the water in the cooling system. One difficulty with antifreeze mixtures is that they tend to evaporate. Another disadvantage is that many of them, when accidentally spilled on the hood, dissolve the paint and spoil the finish of the car.



164. How the muffler reduces the noise of an automobile.

3. Principles of sound are applied in the automobile

Until the automobile came, the approach of a vehicle could almost always be heard at some distance. The turning of wheels, the creaking of wagon springs, the clatter of horses' hoofs or the puff of a steam locomotive sent out sound waves far and wide. The auto, however, is a remarkably quiet vehicle, when you bear in mind that its power is derived from a series of explosions. Its speed is so great that the purr of engine and swish of rubber tires are not heard until the machine is almost on top of you. Hence, a special sound signal had to be developed for the auto. In the beginning reed horns were used, and the driver squeezed a rubber ball in order to sound them. Later, a siren-like disk was used and its operation depended upon the rather violent push of a knob or a lever. To-day most cars use a horn in which a disk is caused to vibrate by an electric motor. The electricity is furnished by the storage battery whenever the driver applies the slightest pressure to the switch at the centre of the steering wheel.

Another interesting application of sound in an automobile is the muffler. It is this device which makes the operation of the engine so quiet. When the exhaust gases escape, they flow into the muffler, where their pressure is quickly reduced before escaping into the air. Figure 164 shows the construction of this device. According to engineers there is no excuse for a noisy automobile. If the muffler is large enough, nearly all sound of escaping gases is deadened. The valve at the entrance to the muffler is for the purpose of shutting off the entrance so that the gases may escape directly into the air. This causes considerable noise, but adds a little to the power. That is why the muffler is frequently " cut out " when the car is climbing a steep hill.

4. Heat principles are applied in the automobile

Gasoline engines are referred to as internal *combustion engines*. The heat expands the burnt gases so that they push the pistons which drive the car. These gases are exactly the ones generated in the burning of most fuels. The carbon in the gasoline combines with the oxygen in the air to form carbon dioxide and carbon monoxide. The hydrogen in the fuel combines with

oxygen to form water vapor or steam. The drops of water which are sometimes seen dripping from the exhaust are from the condensed steam formed during combustion.

We have already learned how necessary it is to remove excess heat from the cylinders, how important it is to keep the engine warm, how the circulation of water and air carries heat away and how an "antifreeze" mixture protects an automobile in cold weather. In the latest automobile models, the heat of combustion is utilized as far as is possible. Instead of carrying it all away, some of the heat is used to warm the air which enters the carburetor and a good deal of it is used to warm the motor.

HOW MUCH DO I REMEMBER?

A

The letters in each of the sentences below are jumbled. If you rearrange these letters you will find that they spell the correct words. Write your answers on a sheet of paper so as not to mar the book.

1. The *Rcemdese,* one of the first successful automobiles, was built by *Malidre.*
2. Other successful automobiles were invented by *Znbe, Savesrol, Snedel* and others.
3. Air blown tires were the invention of *Nuplod.*
4. In our country, the *Yareud* brothers were the first successfully to manufacture automobiles.
5. Progressive assembling of automobile parts was introduced by *Ordf.*
6. The *batcorreur* vaporizes the liquid fuel and mixes it with air.
7. The *lofta* chamber of the carburetor is always kept filled with liquid gasoline.
8. A partial *cuavum* is created around the spray nozzle of the carburetor by the suction of the *notsips* of the cylinders.
9. The rubber tires are full of *rai.*
10. A poisonous gas which issues from the exhaust of an automobile is *bornac noxomdie.*
11. The *tradoria* must always be filled with water.
12. Water is used in the *loicnog* system of the automobile.
13. The water is kept in circulation through the *tradoria* jacket by a *mupp.*
14. The water in the jacket is cooled by the *ari* which is stirred up by the *naf.*
15. The metal walls of the radiator may crack if the water *rezefes.*
16. In order to prevent this, *holaclo* or *nirlegcye* is mixed with the water.
17. *Liteslidd* water must be added to the storage battery.
18. The *ferflum* reduces the pressure of the exhaust gas and prevents a noisy escape into the air.

B

Write your answers for the following on a sheet of paper so as not to mar the book.

1——— 2——— 3——— 4——— 5——— 6——— 7——— 8———

If more automobiles are owned by Americans than by all other people in the world, put M in space 1. If not, put P.

If the automobile was the invention of one man, put B in space 2. If not, put A.

If the automobile necessitated the building of good roads and stimulated business, put Y in space 3. Otherwise, leave this space blank.

If the automobile has created some occupations but has done away with none, put F in space 4. If not, put B.

If the carburetor always works with the same adjustment, put O in space 5. If it needs adjustment to the type of air and the speed of the engine, put A. If only to the type of air put I.

If the modern carburetor is a simple device, put D in space 6. If complicated leave this space blank.

If gasoline is usually forced from the tank to the carburetor by air pressure, put C in space 7. If by water pressure, put I.

If motor-cycle and airplane engines are entirely cooled by water, put T in space 8. If entirely by air, put H. If partly by air and partly by water, leave this space blank.

Write a sentence about the name you now have.

C

1——— 2——— 3——— 4——— 5———

If the fan behind the radiator keeps a current of air moving past the hot metal of the cylinder, put G in space 1. If not, put D.

If one of the problems in the building of the Holland Tunnel was the elimination of the automobiles' waste gases, put R in space 2. If not, put M.

If the cylinder of an overheated engine may crack, put D in space 3. If such cracking may result from the freezing of the water, put L.

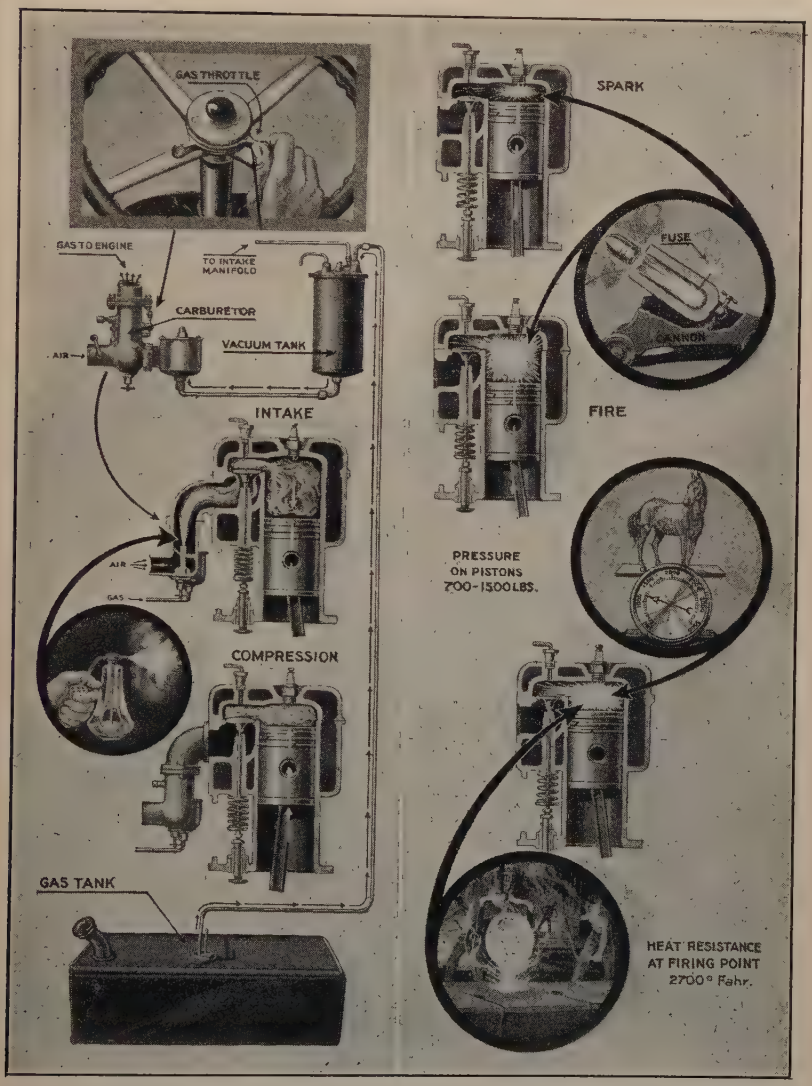
If antifreeze mixtures are placed in the gasoline, put E in space 4. If in the water, put N. If in the oil, put M.

If most drivers use a horn in which a siren wheel is made to turn by the violent push of a lever, put S in space 5. If they use one in which a disk is made to vibrate by an electric motor, put R.

By inserting two vowels in the proper places, you will have the name of a man prominent in the history of the automobile.

THINGS TO THINK ABOUT AND READ ABOUT

1. The following are general references on the automobile.
   The Story of America's First Horseless Carriage.
   Book K, pages 290–292.
   The Story of the Growth of the Motor Truck.
   Book K, pages 481–489.



The above drawings tell a story in which the important steps in the operation of an automobile are compared with the operation of well-known objects. Write a one-page composition which tells this story.

The Story of an Automobile Factory.
Book K, pages 518–538.
Building an Automobile.
Book P, pages 555–571.
The Automobile.
Book O, pages 274–287.
The Rise of the Automobile.
"A Popular History of American Invention," Vol. 1, pages 134–174 (Scribner's).

2. Another good reference is a book called "Automobiles" by J. S. Zerbe (Cupples & Leon Company, New York).
3. American roadways are becoming so crowded with cars that traffic experts are seriously worried about the automobile as a means of rapid transportation. Moreover, the number of accidents is rapidly increasing. In 1929 the number of lives lost because of the automobile was equal to more than half the number of Americans killed during the World War; and in addition, a million people sustained injuries. It is believed that the solution to these problems depends to a large extent upon the proper regulation of traffic. This does not necessarily mean that cars should move more slowly. Some experts think that the solution will come by making it compulsory to keep going at a certain minimum speed, and by strictly prohibiting the passing of other cars. Others think that speeds that are too high should not be allowed. Another important traffic problem is the regulation of crossroad traffic. For this, elaborate systems of automatic traffic lights have been installed throughout the country. You should read "Shall Speed Laws Be Abolished?" in *Popular Science Monthly* for February, 1930. Read also,
Book P, page 86; "Automobiles," pages 169–172.
4. If all the rubber used during 1929 to manufacture tires were made into a single tire, it would have a diameter of more than forty miles. Our country uses more rubber than any other in the world, but it depends on the outside world for raw rubber. You probably know that Edison, at the present time, is experimenting with the growth of rubber producing plants which can be cultivated in our own country. Forty-two years ago there was but one pair of air inflated tires in existence. Dunlop had made these for his son Johnny who wanted to beat a boy in a bicycle race. The success of these tires spurred Dunlop on to further research. He had a hard time convincing manufacturers that they were of value. To-day they are indispensable. The story of the "First Pneumatic Tire" appears in *Popular Science Monthly* for March, 1930. Read also,
Book O, pages 3703–3706; Book K, page 117; "Automobiles," pages 24–36.
5. More about carburetors.
"Automobiles," pages 118–132.

CHAPTER XV

THE AUTOMOBILE (*Continued*)

At the plant of a large automobile manufacturer, not long ago, a new type of motor car was completed. It had been carefully designed and much money had been spent in adding improvements, but the president of the concern was anxious to test it thoroughly before selling a single car of the type.

Two workmen rolled out the new model. The tank was filled with gasoline, fresh oil was poured in, and one of the best drivers took his place at the wheel. The road was a circular track of

166. A testing track for automobiles.

concrete, 2½ miles long, and banked high around the curves. "Drive at 80 miles an hour until we signal you to stop," said the chief engineer.

The car started quickly and smoothly. Round and round it went. An hour passed—two hours, and the car was still circling the track. When the gas was all used up, the car stopped only long enough to get more fuel. After several hours, a new driver got in and continued the dizzy whirl. Night came on, but the signal to stop was not given. The automobile seemed to run more smoothly

than ever. All through the night and for several days and nights thereafter, the test continued. On the fourth day an accident occurred, but strangely enough it was through no fault of the engine.

Several workmen were calmly looking on at the racing car, when it suddenly swerved while on the straight-away. A yell of warning burst from many lips, but the driver did not seem to hear. Just as the machine was about to crash into the fence, the horrified onlookers saw the man inside come to life. They saw him twist furiously at the wheel. The car grazed the fence and then came to a full stop. As the chief engineer ran over to investigate he met the driver climbing out. There was a dazed and sheepish look on the latter's face.

" I guess I fell asleep at the wheel," he said.

It seems that the monotonous grind around the track and the drone of the wind against the car had lulled the poor fellow to sleep. That he escaped death was a miracle.

The long-distance, high-speed test is but one of many that are applied to a new model. There are rough road tests, hill-climbing tests, brake tests, tire tests and other tests which put every strain on the car to which it is subjected when in use. Unless every requirement is met, not a single automobile is sold.

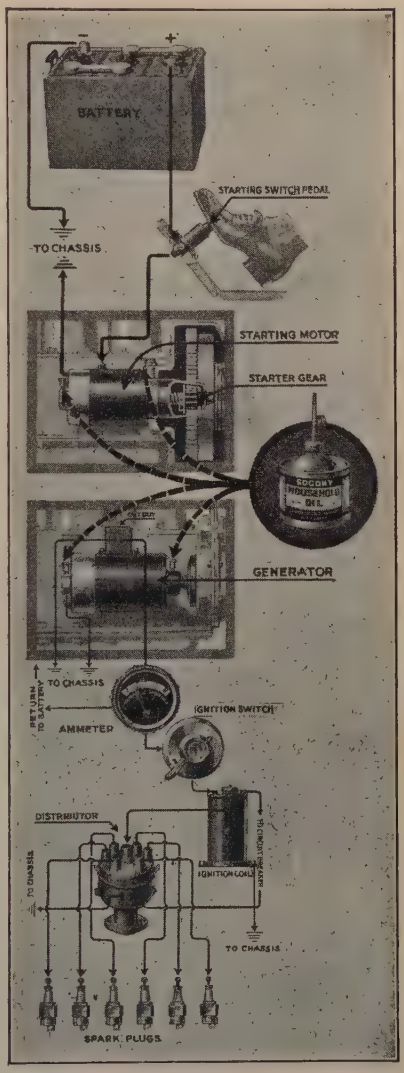
If we compare automobiles of to-day with those used ten years ago, we are amazed at the change in so short a time. The modern vehicle is as beautiful as the old one was ugly. It is faster, more powerful and more economical. The smooth-running engine, balloon tires, improved springs, shock absorbers and upholstered seats make riding to-day very much more pleasant. The four-wheel brakes, the shatter-proof windshields, and the more reliable signal lamps, headlights and steering gear reduce greatly the element of danger. As a result of constant experimentation, we may expect an even superior product in the future.

1. Electricity is essential to the operation of the automobile

The easiest way to put a car out of commission is to tamper with its electric wires. Garage men say that nine-tenths of the minor repair jobs on motor cars involve an adjustment of the electrical

system. Let us see how electrical energy is used in the operation of an automobile.

In the first place, electricity is needed to start the engine, unless one wishes to crank the motor. We learned in Chapter XIII how necessary it is to move the pistons through the intake and compression strokes, before the first power stroke is obtained. In the early days of the automobile, every driver had to start by cranking. Many an arm was broken, and much good humor and patience were lost in this laborious process. Nowadays, the driver presses his foot on a button which closes an electric switch. The flow of current from a storage battery then causes a small but powerful motor to turn around. The motor is geared to the crankshaft, and the crankshaft pushes the pistons up and down in the cylinders. In most cases, a brief touch of foot on switch is sufficient to start the engine. If no explosion occurs, it is because something other than the starter is out of adjustment. It is wise, therefore, to investigate, for if one insists on keeping the switch pressed down, the storage battery may be soon discharged. The great force needed to compress the explosive mixture in the cylinder requires a very



167. Electrical system of an automobile.

large flow of electrical energy from the battery. The latter can supply this energy for brief intervals, but not for continuous running.

Secondly, electricity is needed for the spark plugs. An explosive mixture must be ignited before it will explode, and since there may be as many as twelve cylinders in an automobile engine, an elaborate system of ignition is required.

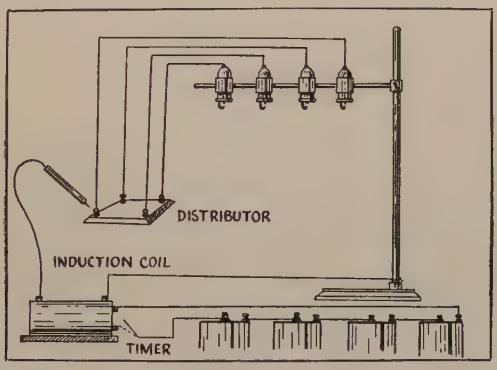
The current which produces a spark at the spark plug must be high voltage current. It takes an electrical pressure of several thousand volts to force electrons across an air gap one inch wide; and although the air gap between the points of a spark plug is only as wide as the thickness of a dime, several hundred volts are nevertheless required. Such voltage is impossible from a storage battery, which usually furnishes a pressure of about 6 volts. Hence, an induction coil is used. As we have already learned, such a coil can change low voltage current into high voltage current.

Another ignition problem is to distribute the high voltage current to all the spark plugs, but not at the same instant to all. The exploding spark must skip around from cylinder to cylinder, so that first one and then another of the pistons receives its power stroke. Furthermore, the spark in each case must occur just at the end of the compression stroke. All this is accomplished by the devices known as the *distributor* and *timer*. In figure 168, you see a model which illustrates the action of these devices.

It can be seen from the above that electricity is needed not only for starting, but also for keeping the engine running. The storage battery would soon be completely discharged if we did not in some way replenish the supply of electrical energy. It is most inconvenient if an automobile stops in the midst of traffic because the battery is " dead." In the early days of radio, the same problem arose. Reception of broadcasts would cease suddenly, and could not be resumed until a new battery was installed or until the old battery was re-charged. The radio problem was solved with the all-electric set, in which the steady house-supply of electricity is substituted for batteries. Unfortunately, an automobile cannot draw on the house-supply. To do so would change the automobile into something like a trolley car; for that is what the latter does, in effect. The next best thing is to provide a separate dynamo

for the automobile. This dynamo generates an independent current supply as it is turned by the movement of the car. Thus, the storage battery furnishes energy with which to start; and, once started, the engine furnishes energy with which to turn the electric generator. From the latter comes the necessary current for sparking the plugs in the cylinders.

The fourth use for electricity in an automobile is to operate the several electric lamps, to sound the horn and to operate such



168. Model of an automobile distributor.

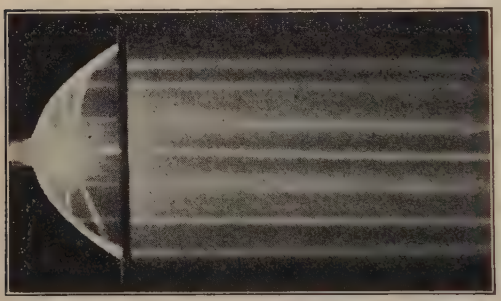
special conveniences as the electric heater in the cab and the cigar-lighter on the dashboard. The strong headlights are essential to night driving, and the red tail light is a protection against collisions. Many automobiles also have a red " stop " light which goes on automatically whenever the brake is applied. This acts as a warning signal to any car which may be following, that the car ahead is about to stop, turn or retard its speed. Several of the instruments on the dashboard are illuminated with electric lamps and some of them are so connected that they do not light unless the tail light is also lighted. In this way, the driver can always know whether the rear lamp is warning the approaching automobile not to come too close.

2. Principles of light are applied in the automobile

In the last paragraph, various uses of electric light in an automobile were explained. The arrangement of these sources of light

rays applies to several of the facts and ideas about light which were studied in Chapters I, II and III.

To begin with, a number of reflectors are provided. A small mirror, either plane or convex, is adjusted so as to give the driver a view of the road in back of him. This is frequently very important, as it indicates the advisability at any time of moving to the right of the road to let another car pass. The headlight reflectors are special concave mirrors. They are of such shape that they cast forward a nearly parallel beam. The beam is focused on a point of the road ahead, which is far enough away to give the driver a chance to stop if necessary.



169. Parallel beam from an automobile headlight.

If the air were always very clear, the beam from auto headlights would spread very little, but frequently, dust and water vapor in the air diffuse the light beam. That is to say, the particles suspended in the air reflect many rays in many directions. The result is that a strong light is cast into the eyes of a driver in a car moving in the opposite direction on the other side of the road. To minimize this danger, the headlight reflectors are covered with lenses which tend to bend the rays to the roadway. The danger of glare to approaching drivers is so great that much effort and experimentation have been devoted to the perfection of headlights. Translucent glass has been tried, also ribbed glass, lamps of different types, opaque hoods or visors attached to the reflectors and many other schemes. There is still a great deal of improvement to be desired. At present, the safest thing to do is to dim the headlights while passing another car moving in the opposite direction. It has become a matter of politeness and courtesy to do so.

Even some of the color principles (see page 99) are made use of in an automobile. The red warning lights are produced by allow-

ing an ordinary electric lamp to send its nearly white rays through a red glass. The latter transmits its own color; namely, red. Red rays are very penetrating and can be seen for large distances.

3. Gravity affects the running of an automobile

One of the first questions that a prospective buyer asks about an automobile is, "How well can this car overcome the force of gravity?" Perhaps he does not use exactly these words. He is more likely to say, "Can she climb hills?" And to this, the salesman probably replies, "Why, Mr. Brown, this is a 90-horsepower engine. Give it a chance and it will climb the side of a wall!" Of course, the salesman is exaggerating the ability of the car, but if we are to be in a position to judge the power of an engine, we need to know what *horsepower* means.

If an engine can lift a weight of 550 *pounds* through a vertical distance of *one foot* and can do this in *one second*, its power is said to be *one* horsepower. A 90-horsepower engine can do 90 times as much work in the same time, or do the same work in $\frac{1}{90}$ of the time.

When a car is travelling on a level stretch of road, all of its power is used to overcome friction; there is no force of gravity to be overcome. Hence, the speed of the car may be easily increased. The moment the road begins to climb up-hill, the engine must, in addition to overcoming friction, lift the weight of car and passengers against the pull of gravity. The speed of travel is therefore decreased. Now, the pull of gravity is directly downward, toward the centre of the earth. Hence, the engine need not exert a pull large enough to lift the entire weight unless the car is to be moved vertically upward (up the side of a wall).

Going down-hill, the engine of an automobile may be shut off; for the force of gravity is sufficient to pull it down. Frequently, the engine of a car is started by letting it roll down-hill. This is often done when the battery is "dead," and the self-starter does not operate. Cranking is very laborious, but letting gravity do the work is easy. As the car rolls down with the ignition switch on and the fuel throttle open, the pistons are forced to compress the explosive mixture until a spark explodes it. Then the engine continues to run on its own power.

HOW MUCH DO I REMEMBER?

A

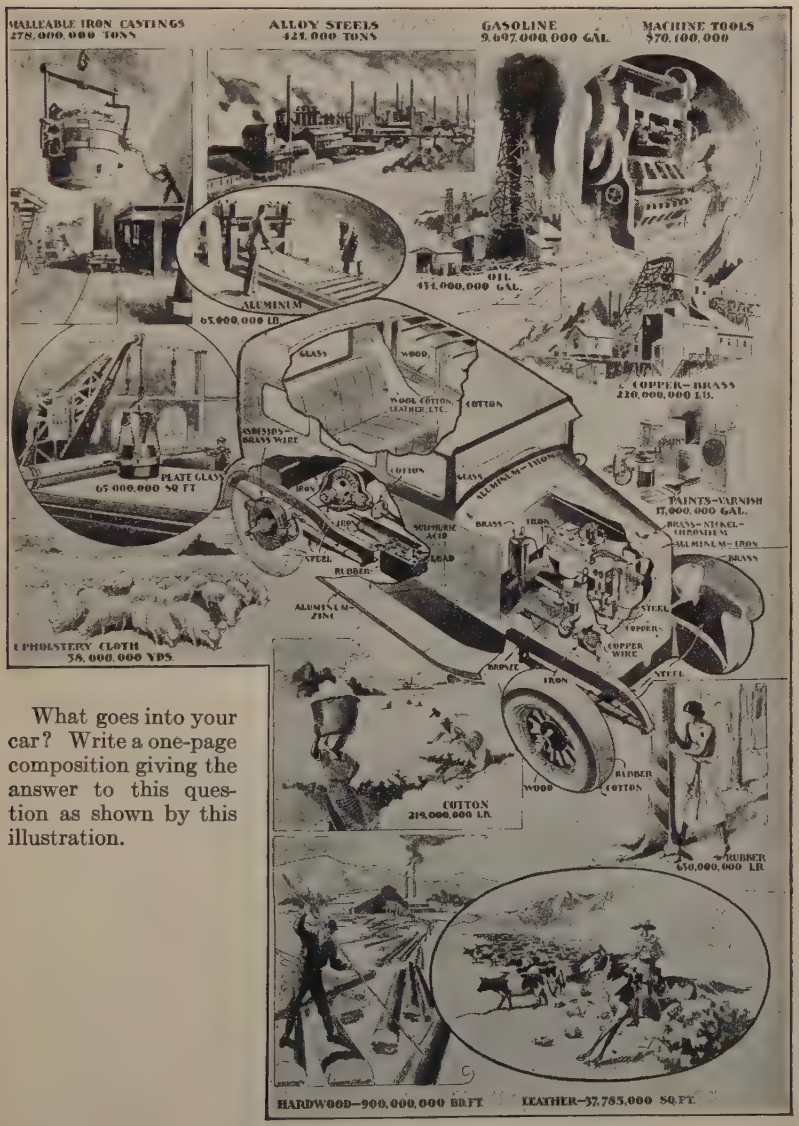
The letters of some words in each of the sentences below are jumbled. Rearrange them on a sheet of paper so as to form the proper words.

1. One of the improvements making for greater comfort in the modern automobile is the use of *kosch serbarsob.*
2. The four-wheel *karbes* on a modern car make it safer.
3. The self-starter of the motor is run by *ticricleyet.*
4. In the early days of the automobile every driver had to start his motor by *nikrangc.*
5. The low voltage current of the *tabyret* is changed into the high voltage current required to produce the spark by means of the *tonnicudi iloc.*
6. The timing of the spark in the various cylinders is accomplished by the *tubstidrior* and *mitre.*
7. The battery of the automobile is charged by a *yamnod* which is turned by the engine.
8. If a battery is overcharged, the driver will turn on the *gildhathes* to use up the excess electrical energy.
9. The electricity from the storage battery is used in the *gatihen* and *gilgnith* devices and in the *nroh* of the car.
10. In many cars there is a *dre tops* light which goes on automatically when the *rekab* is applied.
11. To give the driver a view of the road in back of him a small *rimror* is used.
12. The headlight reflectors are *vacneco rimrors.*
13. The headlight reflectors are covered with *senles* which tend to bend the light to the roadway.
14. The warning lights are produced by sending *hewti* light through *dre* glass.
15. In climbing hills, an automobile must overcome the force of *vagtiry.*
16. When a car is travelling on a level road, all of its power is used to overcome *tonricif.*
17. A car will be able to climb a steeper hill if its *pesroweroh* is greater.
18. In going *nowd lihl,* the engine of an automobile may be shut off.

B

Select the word or words which makes each of the statements below a true statement. Write your answers on a sheet of paper so as not to mar the book.

1. Before selling a car to the public, the manufacturer applies to his model (only a speed test, only hill climbing tests, many different tests).
2. The modern automobile is (faster but not more beautiful, faster and more beautiful, more beautiful but not faster) than the car of 10 years ago.
3. The flow of current from the (battery, generator) turns the electric motor which starts the pistons going.
4. If the engine does not start soon after the starter switch has been closed, this switch (should, should not) be kept closed.



What goes into your car? Write a one-page composition giving the answer to this question as shown by this illustration.

5 Each spark plug sparks at (the same time, a different time).
6. If a driver uses his self-starter too frequently, the battery (may become overcharged, may become discharged, is not affected).
7. If he has been driving the car continuously for a long time the battery (may become overcharged, may become discharged, is not affected).
8. Headlights (are used only on country roads, always burn with the same intensity, may be turned on bright or dim).
9. The mirror which gives the driver a view of the rear is either (plane or concave, plane or convex, concave or convex).
10. The big problem in connection with headlight construction is (to make the road more visible, prevent a glare in the eyes of an approaching driver, save electricity).
11. The diffusion of the headlight beams in all directions is caused by (dust in the air, opaque hoods attached to the reflectors, dimming of the lights).
12. A one-horsepower engine can lift a weight of (1, 550, 90) pounds through a distance of one foot in one second.
13. Since an up-hill road is an inclined plane, the pull of the engine against gravity must be (greater than, equal to, less than) the weight of the car.
14. When a car is coasting down a steep hill, it is best to (apply the brake, shift into "first" and shut off the spark, make no changes).

THINGS TO THINK ABOUT AND READ ABOUT

1. In this chapter you have studied the important part that electricity plays in running an automobile. You have probably seen automobiles that are run entirely by electricity. These cars have no gasoline engines, but they are run by electric motors which get their current from storage batteries. In the ordinary automobile, the storage battery is recharged by the gasoline engine while the car is running. In the electric car, the storage batteries must be taken out frequently to be recharged from some outside source. The electric car is especially valuable because of the space saved and because it is so easy to drive. However, storage batteries are very troublesome. If overcharged, the lead plates have a tendency to buckle. If undercharged, the car may be hopelessly stuck on the road. Also, the speed of electric cars is very limited. The future of the electric car depends on the improvement of the storage battery. Read
"Automobiles," pages 201–214.
2. The generator which produces the current for the automobile is generally a magneto; that is, a dynamo whose magnetic field is produced by permanent magnets. This not only charges the storage battery but produces the sparks for running the engine. Read
Book O, pages 1052, 1404–1405; Book P, page 5161; "Automobiles," pages 133–158.

CHAPTER XVI

THE AUTOMOBILE (*Concluded*)

" Will you teach me how to drive the car, Dad? " asked Fred.

" Why, yes," replied Mr. Lewis. " You are still a little young to take the examination for a driver's license, but you may as well get ready for it."

" That's great! And when I learn I shall be the family chauffeur; so that you and mother can take it easy in the back seat."

" All right, son. Let's begin by finding out how much you already know about automobiles. Answer my questions."

Mr. L.: " What makes an automobile go? "

Fred: " The engine."

Mr. L.: " What kind of engine is it? "

Fred: " It is a six-cylinder gasoline engine."

Mr. L.: " What fuel is used to drive it? "

Fred: " Gasoline."

Mr. L.: " How does this fuel get to the engine? "

Fred: " The liquid gasoline flows from the tank to the carburetor. There it is vaporized and mixed with air. The downward moving pistons suck the mixture into the cylinders when the intake valves are open."

Mr. L.: " What happens to the mixture? "

Fred: " It is compressed by the upward stroke of the piston and exploded by an electric spark which occurs at the right time."

Mr. L.: " When is the right time? "

Fred: " At the end of the compression stroke."

Mr. L.: " Do explosions occur in all cylinders? "

Fred: " Yes, but not at the same time. The explosion skips around from one cylinder to another. Also, the pistons do not all move together. They move in pairs, but the explosion does not occur at the same time in even the two cylinders which are paired."

Mr. L.: " Why is this? "

Fred: "In order to reduce vibration and to get a smooth-running car."

Mr. L.: "How is the spark obtained?"

Fred: "From a storage battery which first sends its current through an induction coil. The coil 'steps up' the voltage to a point where it causes a hot spark at the spark plugs. When the engine is running the current really comes from the generator and through the induction coil to the spark plug."

Mr. L.: "How is the spark timed correctly?"

Fred: "By a timer and distributor which are moved by gears that have the proper number of teeth."

Mr. L.: "How are the valves timed correctly?"

Fred: "By means of the camshaft which is rotated by the same set of gears."

Mr. L.: "Now, tell me what happens to the burnt gases."

Fred: "In each cylinder they are pushed out by the piston when the exhaust valve is open. They then pass into an exhaust pipe and out through the muffler into the air."

Mr. L.: "What is the purpose of the heavy flywheel?"

Fred: "Since only one out of every four strokes of the piston is a power stroke, the engine would run with considerable jerking. The flywheel, however, is heavy; and its inertia keeps it running steadily and smoothly."

Mr. L.: "Should the engine get hot?"

Fred: "A certain amount of heat is good for the engine. The excess heat is carried off by water which circulates from the jacket around the cylinders to the radiator. From the radiator the heat passes off to the air."

Mr. L.: "In addition to gasoline, air and water, what other fluid is essential to the operation of an automobile?"

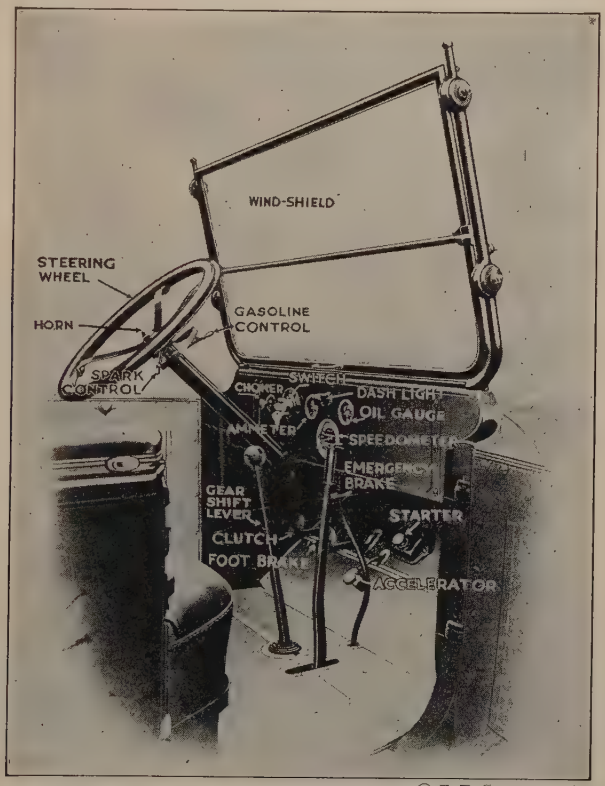
Fred: "Oil. Every moving part of the engine should be thoroughly oiled or greased."

Mr. L.: "That's fine, Fred, you seem to know a good deal about how an automobile runs. I am sure that this knowledge will make it easy for you to learn how to run one. Now, get into the car with me and observe closely everything I do. For every move I make there is an important reason. See if you can give me these reasons."

Fred: "Let's go, Dad!"

Mr. L.: "I close the switch on the dashboard."

Fred: "That is because you wish to complete the circuit between the storage battery and the various devices which it operates."



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171. The brain centre of an automobile.

Mr. L.: "I press this knob with my foot."

Fred: "That must be the self-starter switch which closes the circuit between battery and motor. The motor turns the crankshaft and the engine starts."

Mr. L.: "I push down the accelerator with my foot."

Fred: "You are feeding the engine more fuel, so that it will have sufficient power with which to start."

Mr. L.: "I lower this lever."

Fred: "That's the emergency brake lever. You have released the wheels so that the car can ride."

Mr. L.: "I press down this pedal with my left foot."

Fred: "You have disengaged the clutch, disconnecting the engine from the shaft which drives the rear wheels."

Mr. L.: "I now move this lever into this position."

Fred: "The car is now in 'first speed.' An automobile must be started gradually, otherwise the engine stalls."

Mr. L.: "I gently release the pressure on the left pedal and give the engine a little more fuel."

Fred: "We are now moving at 'first speed,' because you permitted the clutch to connect the engine with the driveshaft. You let in the clutch very slowly so as not to strip the transmission gears, and you stepped on the gas a little in order to get more power with which to overcome the inertia of the car."

Mr. L.: "Now, watch carefully, because the next few moves are going to be made quickly. I speed up the car, press the left pedal again, shift the lever, release the pedal gently and speed up the car again."

Fred: "You have shifted into 'second speed.' After speeding up the car, you disengaged the clutch, changed the position of the transmission lever and let in the clutch without stripping any gears."

Mr. L.: "Right you are. Now, watch again, because I shall repeat the same moves."

Fred: "Now, we are in 'high speed.' The transmission lever is in the 'high' position."

Mr. L.: "Observe what I do with the steering wheel, as we go around the next corner."

Fred: "I noticed that you turned the wheel with steady pressure and that you reversed the wheel's motion in order to straighten out the car."

Mr. L.: "I shall now come to a sudden stop."

Fred: "You shifted your right foot from the accelerator to the brake pedal. Your left foot disengaged the clutch and your right hand shifted the transmission lever to the neutral position."

Mr. L.: "How shall I shut off the engine?"

Fred: "Open the ignition switch, so as to make impossible any further sparking at the spark plugs."

Mr. L.: "If I should now wish to leave the car, may I do so?"

Fred: "Yes, but first put on the emergency brake."

Mr. L.: "Fred, I think you are ready to try to drive by yourself, and I shall now take you to a quiet road where you may begin. You will find that knowing what to do is much easier than actually doing it; but your knowledge will stand you in good stead."

1. Friction helps and hinders the running of an automobile

In Chapter VIII we learned that friction may sometimes aid man in his work, and at other times friction may interfere with and reduce the amount of useful work accomplished. In the operation of an automobile, the force of friction plays a double rôle. It is both a hindrance and a help.

There are so many moving parts in an automobile that the amount of friction is very great. The moving parts tend to wear out and to get hot. For every mile of travel, the pistons slide thousands of times up and down in the cylinders. The heat generated by friction as well as the heat produced by the explosions, expands the pistons and makes them press a little harder against the walls of the cylinders. This would result in even greater friction were it not for the oil which is constantly being splashed up into the cylinders by the crankshaft. Every moving part, in fact, must be oiled or greased. In some cars a special oil pump is provided which forces oil into all bearings and joints. Wherever possible, ball and roller bearings are used to minimize friction; for rolling friction is less than sliding friction. A careful driver watches the oil gauge as carefully as he does the gasoline supply in the tank and the water supply. After every 500 miles of driving, he drains out the old oil and puts in new oil, since the old oil may have in it tiny particles of grit and steel that have been worn away from moving parts. The careful driver is also particular about the kind of oil he uses, because the oil in an automobile must resist high temperatures without burning and must not become gummy when cold. Also, the oil must contain no

172. How the clutch works.

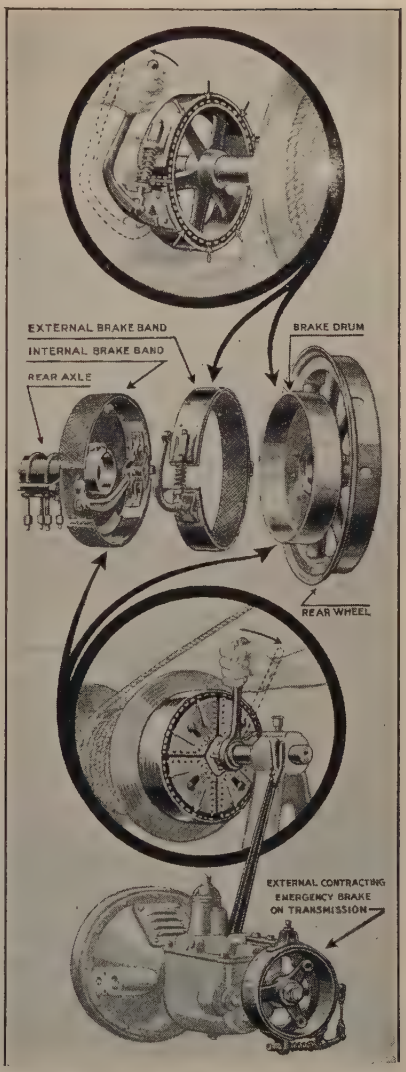
acids that corrode metal. In short, the power obtainable from the engine as well as its length of life is dependent upon the quality and quantity of oil used.

But friction has its important uses in an automobile. The clutch, the brakes and the tires are so constructed as to rely on friction for their operation.

The *clutch* is essential to the running of a car. The driver must frequently disconnect the power of the engine from the shaft which transmits the power to the rear wheels. As we learned on page 224, this is done while shifting gears and also when the car is stopped. Now, the clutch consists of a series of disks (see figure 172) that are pressed together by a spring. This pressure connects the engineshaft with the driveshaft. Friction between the disks makes it possible for the engine to transmit its power to the rear wheels. When the clutch pedal is pushed down, the pressure of the spring is overcome, the disks move apart and the engine runs without affecting the rear wheels at all.

The *brakes* are vital to safety. The modern automobile has a brake on each of the four wheels, and in addition to those which may be operated by the foot pedal there is also the emergency

brake which is operated by hand. Here, too, we depend upon friction. A band of rough material rests against the wheel drum. When put into operation by the driver, the band grips the drum and stops the movement of the wheel. So powerful are the brakes that a car moving at 30 miles an hour can come to a full stop 10 or 15 feet beyond the point where the brakes are first applied. Of course, the brakes loosen up in time and the rough material of the bands wears out. Hence, the careful driver should have the brakes tightened frequently, and, if necessary, the bands should be relined.



173. How the brakes work.

The *tires* of an automobile illustrate another use of friction. If there were no friction between the wheels and the road, the wheels would spin without moving the car. That is what happens on an icy roadway or in some cases on a wet pavement. When an auto skids, it is because there is too little friction between tires and road. The indentations on the rim of a tire and the chain which is sometimes tied around it are for the purpose of increasing friction. Perhaps you have watched men struggling with a car that has been bogged in the mud of a dirt road. In order to

increase the friction under the rear wheels, they place rough materials, such as stones and planks, under the wheels. It is the force of friction which finally makes it possible to get the car out of the mire. In the case of heavy tractors used in farming and in hauling great loads over soft roads, the wheels are studded with sharp blades which dig into the road. The resulting friction retards speed; but the pull is slow and powerful.

2. Inertia principles are applied in the running of an automobile

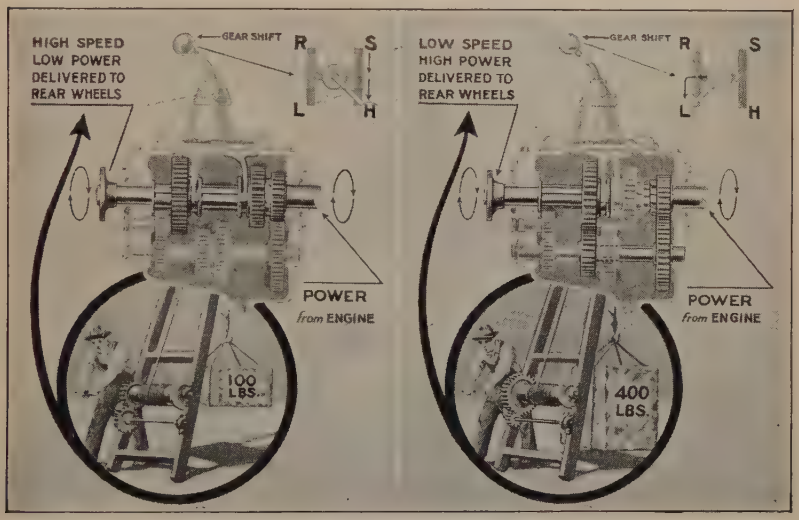
A very common experience, when one is learning to drive, is that of stalling the engine before the car picks up speed. This is due to inertia. As we learned in Chapter IX, a body at rest tends to remain at rest. In order to move it we must exert a force to overcome its inertia. The amount of inertia depends upon how quickly we wish to change from no motion to rapid motion. If this change is slow, the inertia to be overcome is small; if this change is rapid, the inertia to be overcome is great. Hence, an automobile must be started moving slowly; otherwise, the engine cannot exert a sufficiently powerful force to overcome the inertia of car and passengers.

In our description of how to start a car (page 223), Fred's father was careful to increase speed slowly, by shifting gears. Now, why are transmission gears necessary? Driving would surely be a more simple operation without them. Again, it is the principle of inertia which must be considered. When in "first speed" a small gear driven by the engine engages a large gear attached to the drive shaft. The driveshaft, therefore, moves slowly but powerfully and is able to overcome the inertia of the car. Then the engine is fed more fuel. It speeds up. It is time to shift to "second speed." This shift brings two gears together, which are more nearly the same size, and the driveshaft rotates at a faster speed.

Finally, it is time for "high speed." When the shift is made, a large gear driven by the engine engages a small gear attached to the driveshaft. The latter rotates rapidly and imparts its motion to the rear wheels.

Thus, we see that a very complicated system of gears is necessary because of the principle of inertia. Of course, the transmission gears have other uses in driving. The greater pulling

power of a car in " first speed " is made use of in climbing hills or in going over very rough roads. One of the boasts of the owner of an expensive car, is that " it can take any hill ' on high.' " We often hear a motorist say, " The road was up-hill, but I took every hill ' in second.' " As we learned on page 158, rapid motion exerting a small force may be changed to slow motion exerting a large force.



174. Why gears are shifted.

The more powerful the motor, the sooner is the inertia of rest overcome. That is why automobile salesmen speak of the rapid " get-away " of the car which they are trying to sell. In city traffic, the " get-away " or speed " pick-up " is very important, for many accidents may be avoided by changing quickly from rest to motion.

The principle of inertia operates in another way. Once a car is in motion it tends to stay in motion, even after the motor is shut off. The more rapid the motion the greater is the force needed to stop it. Hence, even the most powerful brakes cannot bring a car to a full stop the instant they are applied. The car rolls on for some distance. This fact is borne in mind by the careful driver who travels at high speed. When brakes are applied too suddenly,

the passengers are thrown forward. In accidents caused by quick stops or collisions, the driver is frequently thrown through the windshield, for the inertia of his moving body keeps it going even after the automobile is stopped.

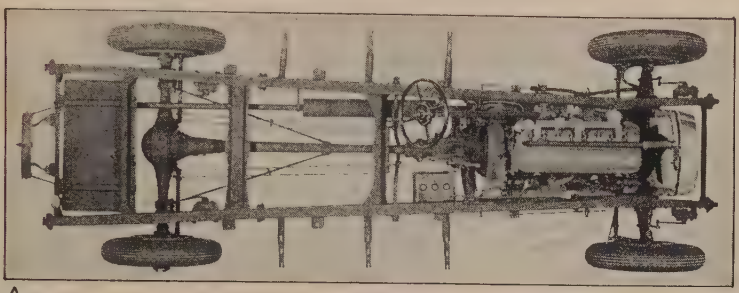
3. Many automobile parts are adaptations of simple machines

The lever, the wheel and axle and the screw are the simple machines which are used in great number in an automobile. The clutch pedal, the brake pedal, the transmission lever and the emergency brake handle are all levers or modifications of levers. The steering wheel, the brake-drums and the many gears are wheels and axles. Examples of the screw may be found in the fan which cools the radiator, in the action of the pump which helps to circulate the water in the jacket around the cylinders, and in the worm-gear which turns the crankshaft when the self-starter motor is operated.

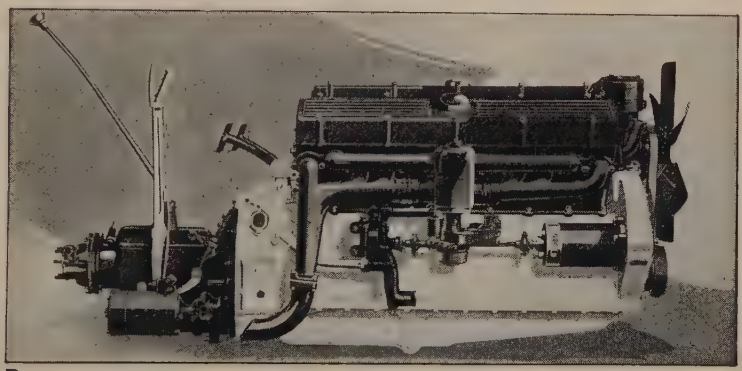
THE AUTOMOBILE AND INDUSTRY

Whether or not we understand the workings of an automobile, it nevertheless affects our lives in many ways. In using the automobile for comfort, convenience and pleasure, we are creating a demand which is revolutionizing modern business. You may appreciate the extent of the automobile's effect on industry, if you can picture to yourself a freight train 25,000 miles long—long enough to encircle the earth at the equator. In this train are the steel, gasoline, oil and other materials needed each year to build and operate America's automobiles.

In far-away forests, men hew giant timbers for the wood that is needed in the automobile. Cattle by the thousand are killed for the necessary leather. Sheep are shorn for their wool. Glass factories pour tons of molten glass into plates for windshields. Blast furnaces are busy day and night, so that there may be plenty of metal for chassis and engine. Copper, brass, aluminum, nickel, paints, varnishes, cotton, rubber and hundreds of other materials are mined or grown or manufactured, as the case may be, to meet the needs of the automobile. Great derricks poke their drills into the depths of the earth in constant search of fuel to feed the millions of gasoline engines. And all so that we may ride!



A



B

C

A. List all the automobile parts which you can identify in this picture.
B. List all the engine parts which you can identify in this picture.
C. Name this automobile part. What is its use and purpose?

HOW MUCH DO I REMEMBER?

A

Pick out the part of the automobile from List X which performs each function described in List Y. Write your answers on a sheet of paper so as not to mar the book.

List Y

1. Makes an automobile go.
2. Is used as fuel in the engine.
3. Is the place where fuel is stored.
4. Is the place where the fuel is vaporized and mixed with air.
5. Admits the fuel into the cylinder.
6. Explodes the fuel and air mixture.
7. Reduces vibrations and gets a smooth running car.
8. Supplies the current for starting the engine.
9. "Steps up" the voltage of the battery current.
10. Supplies the current which recharges the battery while the engine is running.
11. Times the spark to come at the right instant.
12. Times the valves of the cylinder so that they open at the correct times.
13. Admits the exhaust gas into the muffler.
14. Keeps the engine running smoothly because of its inertia.
15. Circulates water around the cylinders.

List X

A. flywheel
B. intake valve
C. camshaft
D. storage battery
E. transmission lever
F. engine
G. clutch
H. gasoline
I. accelerator
J. large number of cylinders
K. exhaust valve
L. ignition switch
M. gas tank
N. jacket
O. timer and distributor
P. steering wheel
Q. emergency brake lever
R. carburetor
S. self-starter switch
T. generator
U. electric spark
V. induction coil
W. radiator

B

Tell whether each of the following is true or false. Write your answers on a sheet of paper so as not to mar the book.

1. The gas mixture is sucked into the cylinders by the moving pistons.
2. The electric spark occurs at the end of the intake stroke.
3. The explosion takes place at the same time in all cylinders.
4. When the engine is running most of the current comes to the spark plugs from the battery.
5. The camshaft and distributor are moved by the same set of gears.
6. A certain amount of heat is good for the engine.
7. The only fluids essential to the operation of an automobile are water, air and gasoline.

8. The circuit is always kept closed between the battery and the devices which it operates.
9. An automobile must be started gradually to prevent stalling.
10. If the clutch is let in too quickly, the transmission gears may be stripped.
11. Friction both helps and hinders the running of an automobile.
12. Every moving part of the mechanism must be oiled or greased.
13. The oil removes the heat accumulated by friction.
14. Ball and roller bearings are used to reduce friction.
15. A good lubricating oil will resist high temperatures and contain certain amounts of acid.

THINGS TO THINK ABOUT AND READ ABOUT

1. The main shaft of Otto's gas engine made about 200 revolutions a minute. This was considered, at the time, the maximum speed an engine could stand; because the faster the motion the greater would be the wear and tear due to friction. To-day, 4,000 revolutions a minute are common in automobile motors. Because of the great speeds of modern cars, the temperature of the engine and oil has become very high. As a result, automotive engineers are constantly experimenting with new lubricants that will not spoil when hot. The automobile requires special oils and will not function with lubricants used in other types of machines. As many as twelve different kinds of oils are made by one manufacturer for use in automobiles. These oils never wear out but they spoil because of the absorption of moisture, dirt and oxygen.
   "Automobiles," pages 180–190.
2. Not all the friction in an automobile is developed internally. The road too is an important factor. One of the solutions to our traffic problem is the building of wider and smoother roads. You may be interested in reading "Roads and Road Making."
   Book O, pages 234, 3024, 3026; Book P, pages 3387–3402.
3. Steering gear and brakes.
   Book O, pages 278, 287; "Automobiles," pages 37–45.
4. The differential and transmission gears—adjustment for "first," "second" or "high speed."
   "Automobiles," pages 46–54, 69–89; Book O, pages 283–287; Book K, page 526.
5. Clutches.
   "Automobiles," pages 62–68.

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